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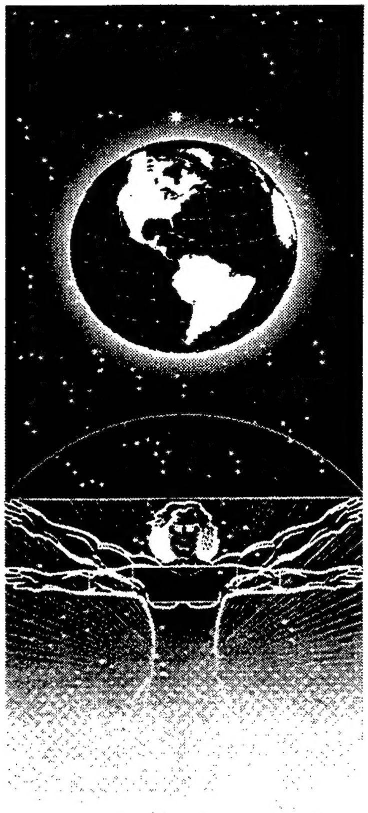

UNITED STATES AIR FORCE RESEARCH LABORATORY

Modular Aircraft Support System (MASS) Aerospace Ground Equipment (AGE) Data Acquisition Final Report

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Acorn Park
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September 2000

Final Report for the Period April 1999 to September 2000

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Human Effectiveness Directorate
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NOTICES

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

ALBERT S. TORIGIAN, Lt Col, USAF
Deputy Chief
Deployment and Sustainment Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

Work performed under Delivery Order 0007 (DO7) of the Modular Aircraft Support System (MASS) program established a testbed for investigation of automated performance data collection/processing and dissemination of resulting information in formats relevant to logistics community users. In the first part of DO7, an MEP-804A 15kW generator set was selected as the testbed. Instrumentation for the generator set was determined by analysis of parameter monitoring requirements and then implemented using existing sensors and simplified installation of new COTS sensors, data acquisition unit, and radio modem. Radio link transmission, to a remote host computer, of captured performance parameter data was demonstrated successfully at AFRL. In the second part of DO7, a web-based server was developed to perform some preliminary analysis on the data from the generator and to broadcast that data wirelessly to remote clients. The Palm computing platform was selected with a wireless modem for the remote client. Contained herein are descriptions of the instrumentation requirements analysis, system hardware/software specifications, equipment installation, tests, and demonstrations which were conducted.

14. SUBJECT TERMS

Aircraft Ground Equipment (AGE)	Sensors	Software	Palm Pilot
Data Acquisition System (DAS)	Diagnostics	Generators	Prognostics
Wireless Communications	Hardware	Wireless Web Access	

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Preface

This report, prepared by staff members of Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts, 02140, is the Final Report, CDRL A003, for the Modular Aircraft Support System (MASS) Aerospace Ground Power Equipment (AGE) Data Acquisition Design Study authorized by Delivery Order 0007 under contract F41624-96-D-5002/0007. All work under the contract was performed for the Air Force Research Laboratory, Wright-Patterson AFB, OH, as guided and directed by the Program Manager, Matthew Tracy. The report summarizes the work performed under Delivery Order 0007 as guided by Captain George Tadda and Captain Rudy Cardona.

The key technical personnel at Arthur D. Little, Inc., who participated in this effort and their areas of responsibility are as follows:

Michael Amato	Mechanical Technician
K. Carignan	Web Application
Allan Chertok (Consultant)	Technical Review
Paul Franzosa	Electrical Design
David Hablanian	DO 7 Program Manager
Scott Harris	Electrical Wiring
Tom Hosmer	Mechanical Design
Gerry Lavoie	Electrical Technician
Grant Lewis	Web Application
Paul McTaggart	MASS Program Manager
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John Wood	System Engineering, Software

Acknowledgment is also given to the following contributors to the program and to this report:

D. Darlington
S. Mulgund
S. Tobin
H. Batchelder (Consultant)
K. Pomerantz (Consultant)
M. Jalbert (Consultant)

The Air Force Research Laboratory (AFRL) envisions that supportability of Aerospace Ground Support Equipment (AGE) can be significantly enhanced by automated performance data collection/processing and dissemination of resulting readiness, prognostic and diagnostic information in formats relevant to logistics community users. These technologies are now widely employed in commercial sector and other military applications and it is anticipated that they can be leveraged for this purpose. As an initial step towards this goal a testbed for demonstrating these concepts was designed, implemented, tested and demonstrated under Delivery Order 0007 (DO7) of the Modular Aircraft Support System (MASS) program which addresses AGE deployment footprint reduction and supportability enhancement.

Delivery Order 0007, issued in April 1999 under subcontract F41624-96-D-5002/0007, directed Arthur D. Little, Inc. (ADL) to develop a retrofitable AGE data acquisition system (DAS) which would enable the AFRL to develop and demonstrate AGE condition assessment by a radio linked remote host station and distribution to a web server for remote wireless access.

AFRL anticipated that an Air Force "–60" gas turbine generator set might be used for the DO7 demonstration program but these units are in short supply and one was not available. Though the cooperative efforts of the Program Manager Mobile Electric Power Office (PM-MEP) an MEP-804A 15kW generator set, was provided to ADL, as Government Furnished Equipment (GFE) as a testbed for the DO7 program. The diesel engine, generator and control systems in this unit provided a comprehensive suite of performance parameters representative of those which might monitored in other types of diesel-powered AGE. The generator set provided by the PM-MEP is depicted in Figure ES-1.

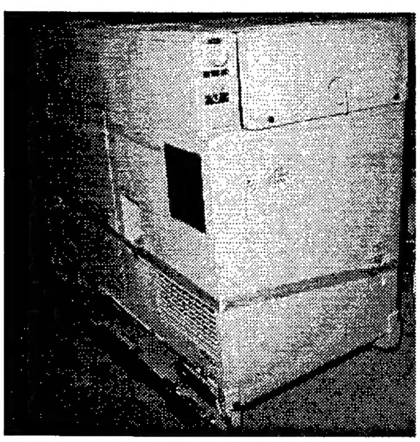

Figure ES-1: MEP-804A 15 kW Generator Set

Executive Summary

Part I – Data Acquisition System Design and Development

Desired instrumentation features for this generator set were determined by analysis of parameter monitoring requirements and then implemented using existing sensors and simplified installation of new COTS sensors, data acquisition unit and radio modem to demonstrate affordability for future deployment. Radio link transmission, to a remote host computer, of captured performance parameter data was successfully demonstrated at AFRL.

Contained herein are descriptions of the instrumentation requirements analysis, system hardware/software specifications, equipment installation, tests, and demonstrations which were conducted.

Work performed under Part I of DO7 consisted of four tasks:
1. Design Study
2. Implementation
3. System Testing at AFRL
4. Reporting

The Design Study was comprised of nine subtasks:
1. Determine performance parameters
2. Establish sensor requirements
3. Establish data acquisition system (DAS) requirements
4. Identify DAS hardware and software
5. Estimate cost to implement DAS hardware and software
6. Recommend Test Bed Configuration
7. Estimate cost of implementing Test Bed Configuration
8. Estimate cost of restoring Test Bed
9. Deliver Design Study Report (CDRL A001)

Implementation required performance of eight subtasks:
1. Develop detailed design specifications (CDRL A002)
2. Packaging design
3. Procure hardware
4. Develop test plans (CDRL A002)
5. Develop software
6. Perform bench test
7. System installation
8. System test at ADL

System Testing at AFRL consisted of three subtasks:
1. Ship test bed to AFRL
2. Systems test at AFRL
3. Revise design specification (CDRL A002)

Reporting encompasses three subtasks:
1. Prepare final report draft (CDRL A003)
2. Final program review
3. Revise final report

Part I of this report includes the following information:
- Design study results
- Detailed specifications
- Test results
- Conclusions and program assessment
- Appendices (sample data, program listing, electrical schematic diagrams, and sensor installation mechanical drawings)

Design Study

Approach
The ADL team used a bottom-up system engineering strategy as shown in Figure ES-2. This approach allowed sequential coverage of all nine subtasks.

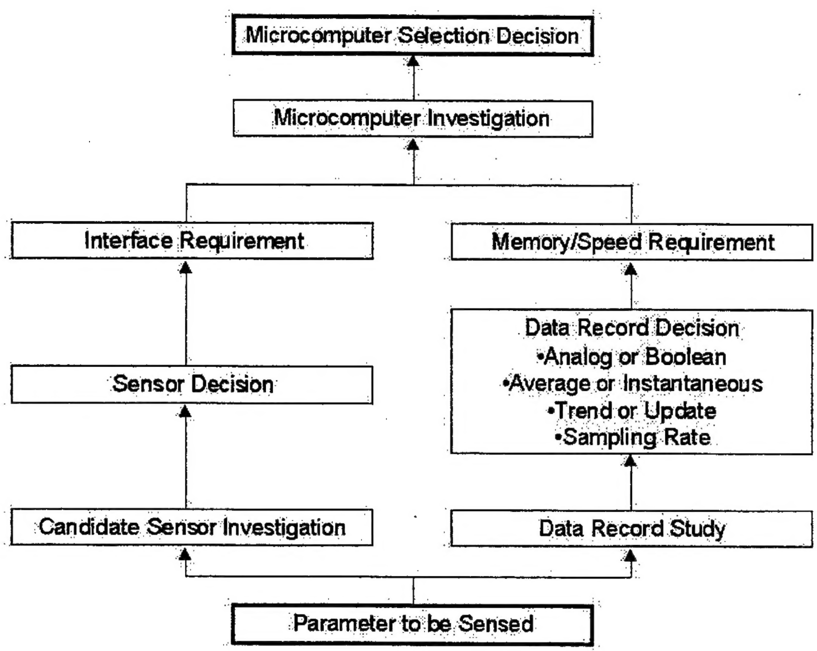

Figure ES-2: Bottom Up Design Strategy

Performance Parameters
The initial task of Delivery Order 0007 was to identify the parameters that would provide the most useful information for engine-generator set health monitoring, condition prognosis, and troubleshooting diagnostics. Selection of parameters used the following criteria as a basis for selection:

- Potential relevance to the three types of desired information (health, prognostic, and diagnostic)
- Cost, including near- and long-term considerations

Section 1 of this report provides information regarding performance parameter selection, assessment, and analysis.

Sensor Requirements and Selection

Following selection of performance parameters, the design team investigated candidate sensors which would enable them to be observed at a remote radio-linked host site. As shown in Figures ES-3 and ES-4, parameters and sensors were identified and separated into two categories: *Recommended* and *Optional*. The recommended sensors are those that scored the highest qualitative ratings. It should be noted that all sensors identified in this report are commercial-off-the-shelf (COTS) products and, as such, presented a low development risk for implementation.

Section 2 of this report provides technical descriptions of the various sensors recommended for parameter measurement. Section 6 provides implementation information describing sensor installation.

	Sensor												
Parameter	Kavlico OD-604-7004	Kavlico P165-100G-E1A	Kavlico P356-5D-E1A	Gems XM-800-51965	Optek OPB770T	OSI 3VT-120A	Vaisala PTB100	Omega TCJNPTU72	Resistive Voltage Divider	Coolant Temperature**	Power Transducer**	Frequency Transducer**	Fuel Quantity**
Oil Quality	√												
Oil Pressure / Differential Pressure*		√											
Coolant Level				√									
Coolant Temperature										√			
Engine Misfire Detection			√		√						√		
Voltage						√							
Current											√		
Frequency									√			√	
Percent Power											√		
Barometric Pressure							√						
Inlet Air Temperature								√					
Fuel Quantity													√
Battery Voltage									√				

Figure ES-3: Sensors/Parameters for Recommended Test Bed (13 parameter system)
*Requires two of the appropriate sensors
**Existing sensor

Parameter	Sensor: Kavlico P165-50G-E1A	Kavlico P356-D1-E1A	SK OL604-9025	Racor 230RP2	Omega TCJNPTU72	Fuel Quantity**	Power Transducer**
Oil Temperature			√				
Fuel Filter Differential Pressure*	√						
Fuel Filter Water Presence				√			
System Specific Fuel Consumption						√	√
Air Filter Differential Pressure		√					
Oil Quantity			√				
Exhaust Temperature					√		

Figure ES-4: Optional Sensors/Parameters
*Requires two of the appropriate sensors
**Existing sensor

Data Acquisition System (DAS) Requirements

The DAS captures sensor data and formats the data for efficient radio-link transmission to a remote host computer site. The DAS consists of hardware and software, including:

- Microcomputer to control acquisition and formatting of sensor data
- Various input ports for receiving the analog and digital sensor signals
- Serial data port to receive host commands and to transmit sensor data
- Radio frequency modem link for establishing communications with a host computer

We implemented DAS functions with a Campbell Scientific CR9000 DAS, which offered the following benefits:

- Met or exceeded all DAS requirements
- Expandable (should investigations beyond the scope of this program require additional sensors and/or memory)
- Commercial off-the shelf (COTS) product

In conjunction with the Campbell CR9000, we used an ADAM-4550 radio modem to implement the radio frequency data link.

Section 3 identifies the DAS hardware and software requirements and recommendations regarding implementation.

Implementation Subtasks

The "Detailed Design Specification and System Test Plan" report (September 13, 1999) provided the mechanical drawings and electrical schematics required to install the sensors, data acquisition system, and RF modems. This information is also provided in Sections 4, 5, and 6 of this report. Test procedures and schematic diagrams were developed as given in Appendices C, D, and E of this report.

The sensors, DAS hardware, and RF modems were procured and installed in the MEP 804A generator set as planned. New wiring was done to provide the connection between the sensors and the DAS. Application software was developed for the DAS to accommodate the selected sensor suite and data sampling policy. Additional DAS application software was configured to provide illustrative host display formats for viewing sensor data.

Testing Subtasks – System Test at AFRL

Testing was performed in three phases. First, bench-top tests were performed to calibrate the sensors. Second, a system test was performed successfully on November 8, 1999 at Arthur D. Little. Finally, a system test was performed successfully at AFRL on December 14, 1999. The test results are described in Section 7.

During preliminary testing at AFRL the RF modem and its closely-coupled 2.4 GHz antenna, (both originally installed inside the generator set cabinet with minimal antenna exposure), were repositioned to the exterior of the cabinet to improve signal transmission and reception. The adjustment resulted in excellent communication between the building and the generator set. The generator was connected to a load bank and operation of the data acquisition system was verified prior to demonstration on December 14, 1999.

Part II – Wireless Data Access System Design

To further demonstrate the strength and promise of the system developed in Part I, a study was undertaken to determine how to take the captured performance data, perform some preliminary analysis on it, and broadcast it wirelessly to remote clients. Each potential user class has a unique set of data they must track. The goal was to demonstrate a system that would capture all such data and make it available to remote users wirelessly via a handheld device.

Work performed under Part II of DO7 consisted of four tasks:
(1) System specification
(2) Generation of the Concept of Operations (CONOPS) document
(3) Hardware Selection
(4) Software Implementation

Executive Summary

System Specification
The system specification included a web-based approach for data retrieval in order to leverage "off-the-shelf" methods for data formatting and transmission of information to clients. These include Hypertext Transport Protocol (HTTP) for data transmission and Hypertext Markup Language (HTML) for data formatting thus allowing the application to remain independent of the client used to view the data.

CONOPS
The CONOPS was originally written by Captain Rudy Cardona of AFRL. It was then modified into two subsequent revisions by Captain Cardona with input from Arthur D. Little. The CONOPS was written as a series of time frames describing the activities of Logistics Group (LG) and Operations Group (OG) personnel during a typical day. Appendix F contains a copy of revision 3.0 of the CONOPS. The intention of this part of DO7 was not to demonstrate the entire CONOPS scenario, but to show feasibility.

Hardware Selection
The Hardware Selection involved the following tasks:
(1) Hardware specification
(2) Research of available wireless clients
(3) Selection of the Palm V with OmniSky wireless modem

We researched the current state-of-the-art in wireless, handheld web access with the understanding this is a proof-of-concept demonstration and the wireless industry is changing rapidly, with new technology coming to market frequently.

Device	Text Paging	Messaging	Web Server Access	Display Size	Comments
Palm VII		√	√	Large	
Palm V with OmniSky Modem	√**	√	√	Large	** Pushed alerts implemented via fifteen minute polling of email
Blackberry	√	√	√*	Small	*Browsing not real time – store-and-forward messaging
Neopoint		√	√	Medium	
PdQ		√	√	Large	

We selected the Palm V with wireless modem from OmniSky as the best fit because of its robust web access, large screen for data display, and email alert capability. It is important to note the hardware selected for the feasibility demonstration is independent of the software implementation. Any of these devices could be used with little change to the implementation.

Software Implementation
A software system was developed to meet the requirements captured from the CONOPS document. The CONOPS describes a situation in which logistics and operations personnel have constant access to key decision-making data. A software system was developed to demonstrate the feasibility of such a situation to exist in the near future.

Executive Summary

The principal requirement was to demonstrate the ability to distribute diagnostic data captured from the MEP-804A generator to remote PDAs using HTML. After investigating a number of implementation options, the Java platform was selected for the implementation of the MASS DO7 demonstration software.

Java offered the following advantages over other implementation options:
(1) Distributed
(2) Object-oriented
(3) Multi-threaded
(4) Network-centric
(5) Standard extensions for web integration

Conclusions and Recommendations

The DO7 Part I project goals were all met as was demonstrated by operation of the instrumentation system to the complete satisfaction of AFRL program management at the Program Review Meeting of December 14, 1999. The generator set was retrofitted with sensors, a DAS unit and radio modem to capture and transmit performance parameter data to a remote host computer. Data provided to this computer could ultimately be used to assess AGE unit state of readiness, predict future maintenance needs or identify reasons for inoperability or substandard performance. During DO7 testing and demonstration performance parameter data was successfully captured, transferred via radio link and stored/displayed on a demonstration host computer.

The second part of DO7 demonstrated the ability to take data from the system defined in the first part and distribute it in an intelligent manner to the appropriate users. Data distributed in this way could be used to inform the users of the state of readiness of the AGE units but also to alert command personnel as to problems in allocation of resources. During Part II testing and demonstration data was tracked via remote wireless Palm Pilots and alerts were sent via email on present conditions based on a specific usage model. While all of the capabilities of this system were demonstrated individually and partially integrated, a complete demonstration was not accomplished die to the difficulties at AFRL's Wright-Patterson AFB with their system's firewall.

A key lesson-learned as a result of the DO7 Part I work is that performance parameter instrumentation can be readily retrofitted to an existing AGE unit without major hardware modifications. An easily configured, highly flexible and expandable general-purpose COTS DAS unit was employed for the DO7 demonstration to minimize program cost and accommodate future research needs. However, a much more economical DAS and integrated radio modem or other data exchange mechanism could be purpose-designed/manufactured for AGE retrofits to achieve an affordable solution for high volume deployment. The potential to leverage low cost COTS microelectronic and sensor technology provides confidence that the envisioned automated AGE condition assessment can be achieved in a cost-effective manner.

A key lesson learned during the second part of DO7 was that a system to distribute data wirelessly in an intelligent manner was feasible. This was attained by leveraging Java

technology during system development and creating a prototype that was flexible, scalable, distributed and platform independent.

The retrofitable AGE instrumentation system installed under the DO7 program provides the AFRL with the desired platform for demonstrating and further developing AGE supportability enhancement concepts.

Key accomplishments of Part I of the Delivery Order 0007 program include:

- Instrumentation of engine and generator parameters which have promise to provide useful readiness, prognostic and diagnostic information
- Instrumentation of oil quality using an advanced technology sensor
- Identification and use of COTs sensors, DAS and radio link modem components to minimize program risk and to demonstrate a path to affordable deployment of this technology in the future
- Identification of simple and minimally invasive means to install new sensors and utilize existing ones

Key accomplishments in Part II of DO7 include:

- Implementation of a Java-based software platform for distribution of data from Part I over the world wide web.
- Selection of a Palm Pilot with a wireless modem for demonstration of the proof of concept of the wireless data distribution

Implementation of a software alert mechanism to send automated emails when AGE status reach a critical threshold.

Recommendations

Our recommendations for leveraging the work successfully performed under DO7 fall under three categories:

(1) Generator Sets – the DO7 MEP-804A generator set should be returned to the MEP as is for further evaluation. Many of the features can be incorporated in future MEP genset developments.

(2) Other AGE – the same approach used for the MEP genset in DO7 could be applied to other powered AGE carts.

(3) Aircraft Maintenance – A similar approach to DO7 can be used as a stepping stone to develop, demonstrate, and evaluate technology to enhance aircraft maintenance. This work could then be part of the effort to reduce aircraft downtime by improving diagnostics capability.

Table of Contents

Part I – Data Acquisition System Design and Development

Part II – Wireless Data Access System Design

List of Figures

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PART I – DATA ACQUISITION SYSTEM DESIGN AND DEVELOPMENT

1. PERFORMANCE PARAMETERS

The initial task of the design study was to identify the parameters that would provide the most useful information for engine-generator set health monitoring, condition prognosis, and troubleshooting diagnostics.

The following definitions clarify the types of information desired.

- *Health* is defined as the instantaneous operational status of the equipment being monitored. It relates to the equipment's immediate readiness for deployment or its need for repair actions.
- *Prognosis* is the assessment of likely future health of a piece of equipment, based on all current information (current health status, history, etc.). Analysis of prognostic information is expected to prevent equipment failure and minimize the frequency of scheduled maintenance actions.
- *Diagnosis* is the determination of the cause of a failure given all available information. Once a failure occurs, diagnostic information can be used to expedite the troubleshooting/repair process.

This section is divided into two subsections. Section 1.1 explains the criteria considered in selecting parameters to monitor. Section 1.2 provides a qualitative rating of the parameters that met the selection criteria.

1.1. Criteria for Parameter Selection

There were several considerations in recommending the parameters to be monitored. These considerations were largely qualitative and are briefly identified below.

- Potential relevance: Parameters had to provide relevant information in regard to at least one of the three types of information (health, prognostic, and/or diagnostic). Ideally, parameters would provide useful information for all three but this was not always possible.
- Reasonable cost for wide-scale deployment with near-term technologies: Most of the relevant parameters identified can be observed with available cost-effective sensors.
- Cost for installation and refurbishment: In most cases, the sensors selected according to the preceding criteria could be installed and removed from the demonstration generator set (MEP-804A) without great expense.

1.2. Parameter Assessment

We identified all parameters determined to be suitable candidates for measurement. Each parameter is ranked with respect to new science, health, prognostic, and diagnostic relevance information. The "new science" rating indicates the opportunity to demonstrate new technology. Measurements of ambient air temperature, barometric pressure, and percent generator output power provide essential baseline information for normalizing observations made with other sensors. These baseline sensors were

recommended for inclusion in any downselection of the complete sensor suite that might be required to meet program budget limitations.

Each parameter ranking was given a qualitative rating on a scale of 1 to 5 in which "5" represented the highest rating, "1" the lowest. An overall rating of each parameter is provided as the sum of the constituent ratings. Figures 1-1, 1-2, and 1-3 provide ratings for the engine, generator, and baseline parameter measurements respectively. Parameters with total ratings of 13 or higher were selected for the Recommended Test Bed configuration. As previously noted, the baseline observations provide a context for interpreting the generator and engine measurements. The relevance ratings in the tables are based upon diesel generator information sources at Arthur D. Little and information provided by Rick Tavares, Logistics Liaison at Fort Bragg, NC.

Parameter	New Science	Health Relevance	Prognostic Relevance	Diagnostic Relevance	Overall Rating
Engine Misfire	5	4	4	4	17
Oil Quality	5	4	4	3	16
Oil Pressure / Differential Pressure	2	4	5	4	15
Coolant Temperature	2	5	5	3	15
Battery Voltage	1	5	5	4	15
Coolant Level	2	4	4	3	13
Fuel Quantity	1	5	4	3	13
Oil Temperature	3	4	3	2	12
Fuel Filter Differential Pressure	3	3	3	3	12
Oil Quantity	1	5	3	3	12
Fuel Filter Water	5	2	2	2	11
System Specific Fuel Consumption	3	3	3	2	11
Exhaust Temperature	3	3	3	2	11
Air Filter Differential Pressure	4	2	2	2	10

Figure 1-1: Functional Relevance of Engine Parameters

Parameter	New Science	Health Relevance	Prognostic Relevance	Diagnostic Relevance	Overall Rating
Voltage (3 Phase)	2	5	3	5	15
Current (3 Phase)	2	5	3	5	15
Frequency	2	5	3	5	15
Percent Power	2	4	3	4	13

Figure 1-2: Functional Relevance of Generator Parameters

Parameter	New Science	Health Relevance	Prognostic Relevance	Diagnostic Relevance	Overall Rating
Barometric Pressure	2	4	3	4	13
Inlet Air Temperature	2	4	3	4	13

Figure 1-3: Functional Relevance of Baseline Parameters

1.2.1 Oil System Parameters

The following four subsections discuss parameters related to engine oil performance. Lubricating oil is a key factor in attaining full-service life from an engine. There are currently two major methods, combined with regular checks of oil level, used to ensure that engine oil is maintained. The first method is regular oil changes which are a key factor in scheduled maintenance. However, this method cannot detect early degradation due to excessive load or contamination. Conversely, oil that still has useable service life is often changed early, resulting in unnecessary waste and man-hours[1]. Laboratory analysis, the second method, addresses both issues but at significant cost. The following parameters attempt to address the issue and allow real-time analysis of engine lubricating oil.

1.2.1.1 Oil Quality

Oil quality provides a qualitative indication of lubricating oil status by using some measurable aspect of the oil. Measurable aspects might include capacitance, pH, or conductivity[1]. Measurement of the oil quality provides health, prognostic, and diagnostic information.

Oil quality is an important measurement of AGE health. A real-time measurement of oil quality could potentially provide a means of determining if the engine oil needs to be changed. This information can be used for prognostics as well. When viewed over time, the rate of degradation could show either normal degradation and allow maintenance to be scheduled for a certain time, or it could indicate contamination of the engine oil[1]. If contamination has occurred, this information may indicate the type of contaminant, (e.g., a coolant leak).

---

[1] DeGaspari, John. Recording Oil's Vital Signs. *Mechanical Engineering*. May 1999, 54-56.

1.2.1.2 Oil Quantity

Oil quantity indicates the level of oil in the oil pan. Regular dip stick checks of engine oil level are used to prevent operation when the level is too low. This, however, is a relatively inaccurate measurement. More accurate information may be gained from better measurement with a greater frequency of checks. More frequent checks reduce risk of engine damage due to operation with insufficient oil.

The level indicates the health at a given time. If it is too low, oil must be added. Checking the oil level accurately and more frequently also provides better prognostic and diagnostic information. Rapid depletion of engine oil may indicate excessive oil burn or a leak that could lead to a potential failure. If a failure has occurred, this information may be used to isolate the failure based upon the rate of depletion.

1.2.1.3 Oil Temperature

Oil temperature has a major effect on engine oil life. High temperatures result in oil viscosity breakdown and shortened oil life. High oil temperatures indicate possible engine malfunction. Extended periods of high oil temperature may indicate engine failure.

Monitoring this parameter could provide a record of engine oil temperature which, when used in conjunction with other parameters, would offer valuable diagnostic information. For example, a comparison of the history of coolant temperature and oil level in conjunction with oil temperature history data could determine the direct cause of failure.

1.2.1.4 Oil Pressure / Filter Differential Pressure

Oil pressure/filter differential pressure is actually two sensors, inlet, and outlet oil pressure working together. The oil pressure is obtained directly from the outlet pressure sensor. The filter differential pressure is obtained by subtracting the outlet sensor reading from the inlet sensor reading. The engine bearings are lubricated with oil under pressure, which is provided by the engine oil pump. If oil pressure drops too low, engine failure may occur. This can be caused by lack of oil, filter clogging, or pump failure. The rate at which this pressure drops may indicate either filter clogging or pump/oil flow failure. The filter removes any particulate contaminants. Monitoring differential pressure may provide a means of determining when the oil filter must be changed.

1.2.2 Fuel System Parameters

The parameters in this subsection provide information pertaining to the fuel system, which delivers fuel to the engine. Fuel contamination may cause poor engine performance and more severe engine malfunction.

1.2.2.1 Fuel Quantity

This parameter indicates the level of fuel remaining in the fuel tank. Maintainers have indicated that an inoperative generator often is caused by fuel starvation. This measurement can provide a much simpler means of assessing a major component of readiness.

1.2.2.2 Fuel Filter Differential Pressure

The fuel filter is an important component in diesel engines. The fuel pressure is obtained directly from the outlet pressure sensor. The filter differential pressure is obtained by subtracting the outlet sensor reading from the inlet sensor reading. Fuel is often contaminated with water and other particles. To provide clean fuel, the filter must be maintained at regular intervals. Monitoring the pressure drop across the fuel filter may provide a means of reducing the maintenance hours used in replacing filters on a scheduled basis and also addressing the issue of premature degradation.

As with the oil pressure/differential pressure measurement of Section 1.2.1.4 above, a measurement of the outlet side of the filter indicates fuel pressure. Loss of fuel pressure may indicate failure of the fuel pump or a restriction in the fuel system.

1.2.2.3 Fuel Filter Water Presence

To prevent any water in the fuel from rapidly plugging the fuel filter, a water separator is incorporated in the fuel system. If water accumulates in the separator, it must be drained by manually opening a valve. An indication of water in the fuel filter water separator could ensure that water is drained as necessary.

The rate at which the water separator fills could also provide useful information regarding fuel quality. If the separator fills rapidly, the fuel is likely contaminated with a large quantity of water. If this occurs over several tanks of fuel, a fuel supply problem could be indicated.

1.2.3 Coolant System Parameters

The coolant system maintains the engine temperature. Continued overheating can greatly reduce the operational life of an engine. Coolant leaks as well as component failures (e.g., thermostat) can result in insufficient cooling. These parameters provide information to help prevent failure and aid in troubleshooting cooling system problems.

1.2.3.1 Coolant Level
Without a sufficient supply of coolant, the engine will overheat and ultimately fail if operation is not discontinued promptly. The presence of coolant can be checked by monitoring the level of coolant in the coolant overflow bottle. The rate of change of the coolant level may be used to indicate a coolant leak. Interviews with maintainers indicate that coolant leaks are very common with the MEP-804A.

1.2.3.2 Coolant Temperature
Coolant temperature is an important measurement for preventing or diagnosing a potentially catastrophic failure. Generally, engine overheating is caused by low coolant level or thermostat failure. The temperature that was reached and the rate at which it was reached can be used to better assess the actual amount of damage. The MEP-804A is equipped with a coolant temperature sensor and gauge. The gauge is not generally monitored during operation so automatic record keeping of the operating temperature should be valuable to maintainers.

1.2.4 General Engine Parameters
The following parameters provide information regarding aspects of engine performance which are not otherwise observable. While measurements of this type are routinely made through the use of shop diagnostic equipment, (i.e., engine emissions tests), on-board sensors for monitoring the aspects of engine performance described below are not yet in widespread use.

1.2.4.1 Engine Misfire Detection
This parameter provides diagnostic information regarding injector clogging or failure and can assist in isolating and identifying other potential engine problems that are difficult to diagnose using normal monitoring techniques. Engine misfire reduces engine output, increases vibration, and degrades exhaust emissions. Kavlico Corporation has developed instrumentation and techniques for detecting engine misfire [2].

1.2.4.2 System Specific Fuel Consumption (lbs. of fuel / kW hour)
The rate of fuel consumption to generate a given amount of power may provide health information about either the engine or the generator. As engine performance declines, more fuel is required to generate the electrical power at a specific load. Generator degradation could cause a similar result.

Due to the difficulty of measuring instantaneous fuel consumption in conventional diesel engines, only an average measurement of specific fuel consumption is potentially cost-effective for retrofit installations. It is envisioned, however, that the ratio of generator output energy (kWH) (observable by integrating the existing MEP-804A power sensor signal) to the fuel mass consumed during the same period (indicated by change in fuel tank level and temperature history) will provide a useful measure of average system efficiency. A downward trend in system efficiency would provide an initial indication

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[2] Park, Kyong M., D.Sc. "The Detection of Automobile Engine Misfire by Monitoring Fluctuation of Exhaust Gas Flow." White paper, Kavlico Corporation, Moorpark, CA, n.d.

that system performance is degrading. When combined with the output of other sensors, this measurement could aid in system diagnostics.

1.2.4.3 Exhaust Temperature

By monitoring the temperature of the exhaust gases from the engine, information reflecting the operating efficiency and the condition of the engine can be gained. For example, a burnt exhaust valve will cause a sharp increase in exhaust temperature.

1.2.5 Engine Electrical Parameters

The engine electrical system is responsible for turning the engine for start up, and for charging the batteries. Without adequate battery charge as indicated by its voltage, the engine cannot be started. The parameter in this section provides a means of monitoring several of the functions of the engine electrical system.

1.2.5.1 Battery Voltage

Battery voltage provides an indication of its charge status and considerable insight into the operation of the engine electrical system. When the engine is not running, the battery voltage should be at some specified level. If the voltage is slightly below this level, a charge may be necessary. If the voltage drops well below a predetermined level, a cell in the battery may be dead and the battery may need to be replaced.

Once the engine is operating, proper operation of the charging system may be verified. The voltage on the batteries should be greater than the rated voltage. If it is not, there is likely a failure of the alternator or voltage regulator or and excessive drain on the battery.

If the battery voltage is normal and the engine fails to start, it is likely there is a failure with the starter system.

1.2.6 Air Intake Parameters

Fuel is mixed with the inlet air to the engine before being burned. The air intake system filters the air to ensure that it is clean prior to ingestion into the cylinders. The parameter below provides information regarding intake air pressure.

1.2.6.1 Air Filter Differential Pressure

To prevent any abrasive particles in the intake air from entering the engine and causing accelerated wear, a filter is provided in the intake duct. This filter has a paper element that slowly accumulates particulates and must be replaced when the accumulation starts to reduce airflow significantly. A dirty air filter can cause engine performance degradation.

1.2.7 Generator Parameters

The parameters in this subsection provide information pertaining to the generator. The generator provides electrical power to the user. It has an output of 120 VAC with a frequency of 60 Hz and is rated at 15 kW. Measurement of these parameters enables assessment of whether the generator set is capable of performing its mission role.

1.2.7.1 Voltage
The output voltage of the generator directly corresponds to its overall operational effectiveness. The output voltage should be at a stable value, nominally 120 VAC phase-to-neutral for each of the three phases under varying load conditions (within the operational parameters). This parameter would be used mainly as a health or diagnostic monitor for failures in the generator control system, such as a failed electronic component or wiring element in its voltage regulator.

1.2.7.2 Current
Generator output current is another measurement that directly corresponds to the overall operational effectiveness. This parameter would be used to check the health of the generator system by monitoring the current in each of the three phases, which should be stable under stable load conditions. An illustrative diagnostic use of this parameter might be to identify a history of inappropriate loading, such as excessive load balance or overload.

1.2.7.3 Frequency
The generator frequency is another parameter that directly corresponds to the overall operational effectiveness of the generator. The frequency should be stable under slowly varying or steady state load conditions. Variations in this parameter could be used to determine generator health or diagnose problems in the engine governor system.

1.2.8 Baseline Parameters
Baseline parameters are those that are used as a reference for, or to derive, another parameter. Engine performance varies widely over different temperature and pressure ranges and to correctly interpret measured performance data it is necessary to have accurate reference environmental information. Derived parameters consist of the baseline measurement and at least one other measurement combined to create a unique parameter. For example, percent power is combined with fuel level to obtain the system specific fuel consumption. We provided sensors for the following baseline parameters.

1.2.8.1 Barometric Pressure
This measurement provided essential information to adjust engine performance measurements that are influenced by barometric pressure.

1.2.8.2 Inlet Air Temperature
This measurement provided information to adjust other measurements that are influenced by ambient air temperature. For example, large fluctuations in battery voltage during starting may be due to extreme cold weather rather than a failing battery.

1.2.8.3 Generator Percent Power Output
The power output of the generator is another parameter that directly corresponds to the overall operational effectiveness of the generator. This measurement can be correlated with root-mean-square (rms) current and voltage measurements to observe the load power factor.

1.2.9 Parameters Not Chosen for Inclusion in this Study

Several parameters mentioned in interviews with maintainers at Ft. Bragg as well as with Mr. Jim Wright of Marathon Electric were considered but were not included in this study due to cost and time constraints.

Maintainers at Ft. Bragg proposed inclusion of sensors for vibration and crankcase pressure. It was suggested that these sensors could be used to differentiate between critical and minor problems. The crankcase pressure could be used to determine when an internal engine malfunction is imminent. The vibration sensor would be used in conjunction with the crankcase sensor to differentiate between internal engine bearing wear and engine mount wear.

Mr. Jim Wright, Applications Engineer with Marathon Electric, a leading manufacturer of brushless AC generators, recommends measuring generator exciter voltage to obtain diagnostic information that would normally not be obtained. For example, a marked increase of excitation voltage noted under a reference load condition (e.g., no load) could be an indicator of failed rotor rectifier diodes or an open exciter winding, while a gradual increase suggests shorted field winding turns.

2. SENSOR IDENTIFICATION

We identified the various sensors necessary to implement monitoring of parameters described in Section 1.2. The following subsections describe the sensors selected to implement those parameters. Section 2.1 incorporates tables describing both the selected and optional sensors. Section 2.2 describes technical descriptions of the selected sensors.

2.1. Parameter / Sensor Cross Reference

Some of the sensors required to measure selected parameters were already installed as standard equipment in the MEP-804A generator set, while others had to be added. Some parameters share sensors. Figures 2-1 and 2-2 provide a cross-reference for determining which sensors are required to measure a parameter. Parameters are listed by table row and sensors by column. New sensors are identified by sensor name and are listed in the first nine columns with shaded headings. The four existing sensors – fuel quantity, power, coolant temperature, and frequency – are presented in the remaining columns. Specifications of new sensors can be found in Section 2.2.

	Sensor												
Parameter	Kavlico OD-604-7004	Kavlico P165-100G-E1A	Kavlico P356-5D-E1A	Gems XM-800-51965	Optek OPB770T	OSI 3VT-120A	Vaisala PTB100	Omega TCJNPTU72	Resistive Divider	Coolant Temperature	Power Transducer	Frequency Transducer	Fuel Quantity
Oil Quality	√												
Oil Pressure / Differential Pressure*		√											
Coolant Level				√									
Coolant Temperature										√			
Engine Misfire Detection			√		√						√		
Voltage						√							
Current											√		
Frequency									√			√	
Percent Power											√		
Barometric Pressure							√						
Inlet Air Temperature								√					
Fuel Quantity													√
Battery Voltage									√				

Figure 2-1: Sensors/Parameters Selected for the Test Bed (13-parameter system)

*Requires two of the appropriate sensors

Parameter	Sensor: Kavlico P165-50G-E1A	Kavlico P356-D1-E1A	Kavlico SK OL604-9025	Racor 230RP2	Omega TCJNPTU72	Fuel Quantity	Power Transducer
Oil Temperature			√				
Fuel Filter Differential Pressure*	√						
Fuel Filter Water Presence				√			
System Specific Fuel Consumption						√	√
Air Filter Differential Pressure		√					
Oil Quantity			√				
Exhaust Temperature					√		

Figure 2-2: Optional Sensors/Parameters
*Requires two of the appropriate sensors

2.2. Sensor Technical Descriptions

This section provides detailed technical descriptions of the various sensors considered for parameter measurement. Please refer to section four for cost information.

2.2.1 Kavlico Oil Quality Sensor OD-604-7004

The oil quality sensor developed by Kavlico provides an indication of engine lubricating oil quality by measuring its dielectric constant. The dielectric constant is determined by measuring the electrical capacitance existing between sensor electrodes immersed in the oil. As the engine oil degrades over time, the dielectric constant of the oil will change. This change is measured electrically and reported as a signal that ranges from 0.5 to 4.5 volts DC. The sensor is compensated to reduce variations of the output due to temperature.

The sensor can be used to distinguish different modes of degradation if the output is observed over time. Normal degradation occurs slowly. However, if oil quality is compromised by unusual contamination (e.g., coolant leaking through a deteriorated head gasket) the rate of change of the dielectric constant will be much faster. Figure 2-3 provides specifications for the sensor.

Specifications	
Supply Voltage	4.75 to 5.25 VDC
Supply Current	10 mA max.
Full Scale Output	4.5 VDC
Zero Scale Output	0.5 VDC
Operating Temperature	-40 to 125 °C
Dielectric Constant Range	2.16 to 3.20 (custom)*
Electrical Characteristics	
Load	10K ohms min.
Error	+/- 1.5% full scale/supply
Physical Characteristics	
Weight	3.5 oz. max.
Length	75 mm
Height	31.8 mm
Width	31.8 mm
Availability	
Lead Time	6-8 weeks

Figure 2-3: Oil Quantity Sensor Specifications

* Kavlico will calibrate sensors using customer-provided samples of new and deteriorated oil. Means to avoid the need for oil-specific calibration of this sensor could be investigated during follow-on work with the test bed configuration.

2.2.2 Kavlico Fluid Level/Temperature Sensor SK OL604-9025

The oil quantity sensor is a fluid level sensor that has an optional built-in temperature transducer. The oil level is measured with a capacitive sensing element while a thermistor is used to report temperature. Figure 2-4 provides the specification for the sensor.

Specifications	
Level Sensor	
Supply Voltage	4.75 to 5.25 VDC
Supply Current	10 mA max.
Full Scale Output	4.5 VDC
Zero Scale Output	0.5 VDC
Operating Temperature	-40 to 125 °C
Temperature Sensor	
Resistance (-40°F)	3821 ohms
Resistance (140°F)	52.2 ohms
Electrical Characteristics	
Level Sensor	
Load	10K ohms min.
Error	+/- 1.5% full scale/supply
Temperature Sensor	
Excitation	10 mA max.
Physical Characteristics	
Weight	TBD
Length	TBD
Height	400 mm
Width	34.9 mm
Availability	
Lead Time	6-8 weeks

Figure 2-4: Oil Quantity/Temperature Sensor Specifications

2.2.3 Kavlico Pressure Sensor P165-xxxG-E1A

The Kavlico P165 pressure transducer was used to measure fluid pressure. It was used for both fuel and oil pressure measurements with the only difference being the specified pressure rating. The specifications apply to both the –50 and –100 model pressure sensors. The –50 indicates a 50 psi range sensor for fuel pressure and the –100 indicates a 100 psi range sensor selected for oil pressure. Figure 2-5 provides the specification for the sensor.

Specifications	
Supply Voltage	4.75 to 5.25 VDC
Supply Current	5 mA max.
Full Scale Output	4.5 VDC
Zero Scale Output	0.5 VDC
Operating Temperature	-40 to 125 °C
Electrical Characteristics	
Output Impedance	100 ohms max.
Error	+/- 0.4% full scale/supply
Physical Characteristics	
Weight	4.5 oz max.
Length	65 mm
Height	31.8 mm
Width	31.8 mm
Availability	
Lead Time	6-8 weeks

Figure 2-5: Fluid Pressure Sensor Specifications

2.2.4 Kavlico Low Pressure Differential Pressure Transducer P356-xxx-E1A1

The Kavlico P356 pressure transducer is rated for measurement of low pressure dry media. It was used for both exhaust and differential air pressure measurements with the only difference being the specified pressure rating. The specifications apply to both the –5 and –D1 model pressure sensors. The –5 indicates 5 psi and the –D1 indicates –1 to 1 psi ratings selected for exhaust and differential air pressure measurements respectively. Figure 2-6 provides the specifications for the sensor.

Specifications	
Supply Voltage	4.75 to 5.25 VDC
Supply Current	5 mA max.
Full Scale Output	4.5 VDC
Zero Scale Output	0.5 VDC
Operating Temperature	-40 to 125 °C
Electrical Characteristics	
Output Impedance	300 ohms max.
Error	+/- 3% full Scale/supply
Physical Characteristics	
Weight	4.5 oz max.
Length	2.22 in.
Height	1.5 in.
Width	1.5 in.
Availability	
Lead Time	6-8 weeks

Figure 2-6: Low Pressure Differential Sensor Specifications

2.2.5 Gems Mechanical Liquid Level Sensor XM-800-51965

A Gems mechanical liquid level sensor was used to monitor engine coolant level. An electronic capacitive sensor manufactured by Kavlico was also considered but rejected because it would not work in a conductive medium such as engine coolant. Other electronic liquid level sensors might be compatible with conductive coolant and investigation of a non-mechanical solution is recommended for future work. The selected mechanical sensor provides continuous level measurement over a specified range. It can be mounted in the top or bottom of the container. Figure 2-7 provides the specifications for the sensor.

Specifications	
Supply Voltage	8 to 24 VDC
Supply Current	20 mA max.
Full Scale Output	5.0 VDC
Zero Scale Output	0.5 VDC
Operating Temperature	-40 to 110 °C
Physical Characteristics	
Weight	Determined during implementation
Length	Determined during implementation
Height	3 in.
Width	3 in.
Availability	
Lead Time	4 weeks

Figure 2-7: Mechanical Level Sensor Specifications

2.2.6 Optek Optical Sensor OPB770T

A reflective electro-optical sensor unit was used for detecting an engine timing mark on the fan belt pulley. The developed timing signal can be used to identify a misfiring cylinder. The timing signal also provides an alternative means of monitoring engine speed. This sensor is comprised of two components: a light source/sensing unit and a reflector. The device will provide a signal output when the reflector is directly in front of the source-sensor unit. An optical sensor was selected to minimize installation cost for this proof-of-concept program. Investigation of more robust electromagnetic timing sensors is recommended for future work. Figure 2-8 provides the specifications for selected electro-optical sensor.

Specifications	
Supply Voltage	5 VDC
Supply Current	40 mA max.
Full Scale Output	Supply
Zero Scale Output	0 V
Physical Characteristics	
Length	0.26 in.
Height	0.43 in.
Width	0.76 in.
Availability	
Lead Time	1 week

Figure 2-8: Optical Sensor Specifications

2.2.7 Racor Fuel Filter with Water Separator Indicator Option 230RP2

The fuel filter manufactured by Racor provides an optional switch indication when the water in the fuel separator has reached a certain level, indicating that the separator needs to be drained. Addition of this indication feature requires replacement of the existing fuel filter assembly. The indicator requires connection to a signal-conditioning device that provides a digital output based on the water level in the separator. The following Figure provides relevant specifications for the signal conditioner.

Specifications	
Supply Voltage	12 to 24 VDC
Supply Current	50 mA max.
Full Scale Output	Supply
Zero Scale Output	0 V
Physical Characteristics	
Length	4 in.
Height	4 in.
Width	4 in.
Availability	
Lead Time	2 weeks

Figure 2-9: Fuel Filter with Water Separator Interface Specifications

2.2.8 Ohio Semitronics 3-Phase Voltage Transducer 3VT-120A

This transducer simultaneously measures the voltage from three separate phases referenced to an AC neutral line. It is configured for 0 to 1 mA output and operation with three LRB5000 current-to-voltage converters to achieve a 0 to 5 VDC signal. It uses the line voltage as a power source to energize its circuitry. Figure 2-10 provides specifications for the voltage transducer.

Specifications	
Supply Voltage	line
Supply Current	100 mA max.
Full Scale Output	5 VDC
Zero	0 VDC
Electrical Characteristics	
Output Impedance	300 ohms max.
Accuracy	+/- 0.25% FS @ 60 Hz +/-0.5% FS over frequency range
Physical Characteristics	
Weight	2.0 lbs
Length	4.75 in.
Height	5.5 in.
Width	3.375 in.
Availability	
Lead Time	2 weeks

Figure 2-10: Phase Voltage Transducer Specifications

2.2.9 Vaisala Barometric Pressure Transducer PTB100

This Vaisala PTB100 series analog barometer is designed to be accurate over a broad temperature and pressure range. It uses the Vaisala BAROCAP silicon capacitive absolute pressure sensor that combines the elasticity characteristics and mechanical stability of single crystal silicon with the industry standard capacitive detection principle. Figure 2-11 provides specification for the barometric pressure sensor.

Specifications	
Supply Voltage	10-30 VDC
Supply Current	4 mA max.
Full Scale Output	5 VDC
Zero	0 VDC
Electrical Characteristics	
Output Impedance	10k ohm / 47nF max.
Accuracy	+/- 2.5 hPa max
Linearity	+/- 0.25 hPa
Physical Characteristics	
Weight	<0.5 lbs
Length	3.0 in.
Height	0.86 in.
Width	2.36 in.
Availability	
Lead Time	2 weeks

Figure 2-11: Barometric Pressure Sensor Specifications

3. DATA ACQUISITION SYSTEM (DAS) REQUIREMENTS

The data acquisition system (DAS) consists of a microcomputer, software to control data collection from sensors connected to its inputs, and a radio frequency (RF) link for communications with a host PC. This section describes the requirements of the hardware, software, and DAS components. Section 3.1 describes the hardware requirements, Section 3.2 describes the software requirements, and Section 3.3 describes the selected DAS.

3.1. Hardware Requirements

The hardware consists of three sections, the microcomputer system with an I/O subsystem and a radio frequency link. Figure 3-1 shows a block diagram of the data acquisition system hardware and its connection to the remainder of the system.

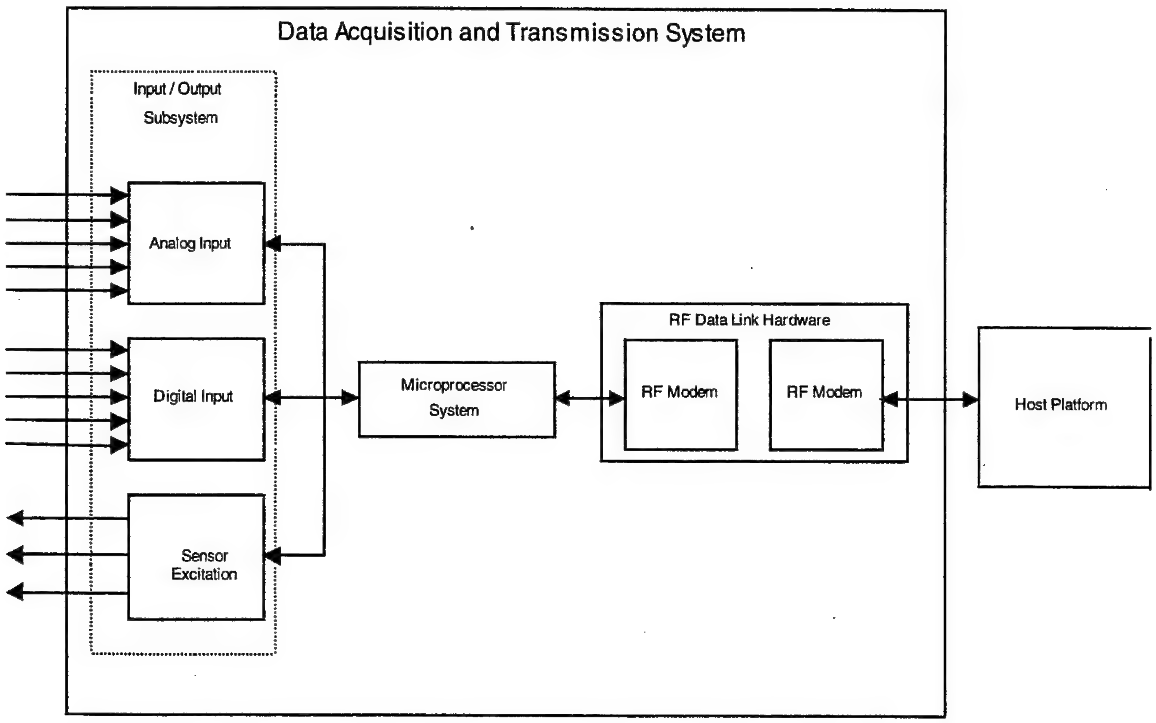

Figure 3-1: Data Acquisition and Transmission System Block Diagram

3.1.1 Microcomputer System

The microcomputer system must be capable of interfacing with both the radio frequency data link and the input/output circuits. The system controls all data acquisition and storage, and reports stored data to the host platform via the RF link. This section details the requirements of the microcomputer system.

The microcomputer system has three major design issues:

- Input/output capability
- Available data memory
- Sampling rate

Each of these design criteria is based upon the number and types of sensors selected for implementation. The Campbell Scientific DAS provided for the testbed has more capability than that required by the existing suite of sensors, therefore, providing room for expansion, if desired.

3.1.1.1 Input/Output (I/O) Capability

The I/O section of the microcomputer system could be implemented in one of two ways or a combination of the two, depending upon the system. The first method would place all the input/output channels on the same board as the micro-computer. This would limit the expandability of the system but would reduce the input/output system to signal protection and sensor signal filtering as necessary. This architecture would be appropriate for a cost-effective manufacturing design for wide-scale deployment. The second method, considered more appropriate for the present stage of concept development and demonstration, would utilize external data acquisition boards interconnected by some form of bus architecture (i.e., serial, universal serial bus [USB], or parallel expansion bus such as industry standard architecture [ISA]). We adopted this latter architecture which is implemented by the Campbell Scientific CR9000 DAS selected for the testbed. This system uses a modular hardware architecture that provides sufficient sensor inputs and memory capability to support the entire suite of sensors discussed in Sections 1 and 2. The Campbell Scientific CR9000 is expandable should investigations beyond the scope of this program require additional sensors and memory capacity.

Two types of inputs and one type of output are required for the system. Analog inputs would be selected to be a high-level range of 0 to 5 volts or 0 to 50 volts to minimize noise susceptibility problems. Some analog sensors would not provide a voltage but simply would vary in resistance over a calibrated range. To perform measurements with these resistive devices, a calibrated sensor excitation voltage would be required. Digital inputs would be required for sensing the state of warning and fault switches.

Figure 3-2 provides a complete breakdown of the parameters being sensed and the required I/O to implement the system. In some cases, inputs may be used by more than one parameter; in this case, number of unshared inputs is indicated by parentheses.

Parameter	Analog Input (0-5 V)	Analog Input (0-50 V)	Digital Input	Analog Output
Oil Quality	1	0	0	0
Oil Quantity	1	0	0	0
Oil Temperature	1	0	0	1
Oil Pressure	2	0	0	0
Fuel Quantity	0	1	0	0
Fuel Filter Differential Pressure	2	0	0	0
Fuel Filter Water Indicator	0	0	1	0
Engine RPM	1	0	0	0
Coolant Level	1	0	0	0
Coolant Temperature	0	1	0	1
Engine Misfire Detection	3(1)	0	0	0
System Specific Fuel Consumption	2(0)	0	0	0
Battery Voltage	1	0	0	0
Exhaust Temperature	1	0	0	0
Voltage	3	0	0	0
Current	3	0	0	0
Frequency	1	0	0	0
Percent Power	1	0	0	0
Barometric Pressure	1	0	0	0
Inlet Air Temperature	1	0	0	0
Totals	**26**	**2**	**1**	**2**

Figure 3-2: Input / Output Requirements

3.1.1.2 Memory Requirements

We estimated the on-board memory requirements for the Campbell Scientific CR9000 Measurement and Control system, which is controlled via the PC9000 program generator software. We also estimated the time required to download a data set from the monitored generator set to the host computer. The following assumptions and requirements underlie these estimates:

- Data will be downloaded from the generator to the host at intervals of no more than 30 hours (essentially once per day, with an allowance for some variation in the download schedule).
- The generator will be operating for the full 30-hour period between downloads, thereby providing a conservative estimate of the memory requirements.
- The wireless modem used for download operates at 9600 baud.
- All 20 of the sensors described in Section 3 are installed and in use at all times.

To provide a starting point for the sampling strategy, the sensors were grouped according to desired sampling rate and sampling window duration. This provides a convenient approach to using the PC9000 software, which allows the user to organize output tables according to some set of criteria (e.g., sampling rate, triggering events, etc.). Each data table would contain approximately 1.2 kilobytes of header information. A data compression strategy would reduce the amount of memory required by omitting timestamps on each data frame. The timestamp would be computed during post-processing using the sampling interval that was used to construct the data table, and the date/time of the first sample. This strategy would considerably reduce the amount of

overhead information in each data table; were it not used, an extra 12 bytes of information would be required for each data frame in each table. Each sensor measurement would be stored using a 4-byte (32-bit) floating-point representation.

Figure 3-3 groups all of the sensors described in Section 2 according to anticipated sampling rate and sampling window duration, and provides the estimate of the total amount of memory required for datalogging. The sampling rates were chosen to capture enough trend information on the measured variable for diagnostic purposes (given the variable's expected dynamic behavior), without collecting a superfluous amount of data. With the exception of the engine misfire detector and the fuel filter water indicator, a 30-hour log of each sensor output was assumed. In the case of the engine misfire detector, it was determined that a one-second snapshot of exhaust manifold pressure would provide enough data to observe any misfire behavior repeatedly; at a speed of 1,800 RPM, one second of data amounts to 30 engine revolutions. This would provide information to compute, for example, a percent misfire rate. The triggering of the fuel filter water indicator would be a discrete event; once a fuel filter water drain service condition is detected by the sensor, there would be no need to make further records of that information. For the purposes of this estimate, it was assumed that the sensor is triggered at some point during the 30-hour window.

The contents of the fourth column in Figure 3-3 (the maximum memory required for raw data storage) were computed by multiplying the number of sensors in the group by the product of the sampling rate and the size of the sampling window (using appropriate units). The resultant quantity represents the number of floating-point quantities that are stored in each table, which is multiplied by four to determine the number of bytes needed for storage. The contents of the last column were computed by adding the amount of header information in each table (1.2k or 1229 bytes) to the preceding column. The resultant estimate of the total memory required for datalogging is 29,390 bytes. At a modem speed of 9600 baud (960 bytes/sec), this much information would require approximately 30 seconds to be downloaded from the generator to the host computer.

Sensors	Sampling Rate	Size of Sampling Window	Maximum memory for raw data storage (bytes)	Total output table size (bytes)
1) Oil quantity 2) Oil quality 3) Oil filter differential pressure 4) Fuel filter differential pressure 5) Coolant level 6) System-specific fuel consumption	1x per 6 hours	30 hours	120	1,350
1) Oil temperature 2) Fuel quantity 3) Coolant temperature 4) Battery voltage 5) Exhaust temperature 6) Generator voltage 7) Generator current 8) Generator frequency 9) Generator percent power 10) Barometric pressure 11) Inlet air temperature	6x per hour	30 hours	7,920	9,150
1) Oil pressure	60x per hour	30 hours	7,200	8,430
Engine misfire detector, which provides two signals: 1) Exhaust manifold pressure 2) Crankshaft position	1 kHz	1 second	8,000	9,230
1) Fuel filter water indicator	Conditional: store output only if short occurs	One data sample	4	1,230
Estimate of total memory required (bytes):				29,390

Figure 3-3: Memory Requirements for Datalogging

Given that the baseline configuration of the CR9000 provides 2 MB of flash memory and 2 MB of SRAM (either of which can be used for datalogging), there was no need for expansion memory at this time. Considerably higher sampling rates could be used before challenging the memory limits of the baseline configuration. However, this may change once some experience is gained in using the system, which should provide greater insight into what data capture strategies will provide adequate diagnostic and prognostic information. For example, once off-nominal conditions are detected, it may be desirable to increase the sampling rate on one or more sensors to capture more fine-scale behavior. Should a problem be detected and corrected, the normal sampling rates could then be resumed. The PC9000 software does support such event-based datalogging.

3.1.2 Radio Frequency (RF) Data Link

The radio frequency (RF) data link is comprised of two data modulators-demodulators (modems) and two antennas. Figure 3-4 lists the requirements for the operational requirements of the RF link.

Parameter	Minimum	Maximum	Comments
Frequency	2400 MHz	2483.5 MHz	As per e-mail dated 6/3/99, from Capt. G. Tadda, AFRL
Range	~200 ft.	N/A	Between Bldgs. 190 and 434, WPAFB, Dayton, OH
Baud Rate	9600	N/A	

Figure 3-4: Radio Frequency Link Operational Requirements

The RF modems were capable of interfacing with the RS-232 serial data ports of the Campbell CR9000 DAS and the host platform. Both the DAS and the host used a 9-Pin RS-232 serial data port. Selecting an RF modem link which was interchangeable with a standard RS-232 hard-wired data link between the DAS and host enabled use of COTS software provided by Campbell Scientific.

3.2. Software Requirements

Depending upon the hardware selection, the software task could range from the challenging development of a complete microcomputer software system to simply configuring an application for a COTS software controlled data acquisition product. We determined that the latter approach significantly reduced the time required to develop the DAS system for this program and facilitate implementation of additional features or changes in the future. The Campbell Scientific CR9000 DAS enabled this approach and this feature provided significant motivation for selecting this unit.

The requirements of the DAS software system were as follows:

- Allow for continuous polling of inputs
- Allow for trigger-based data storage
- Allow remote modification of sampling parameters
- Provide RS-232 communications with host
- Buffer data between upload periods

We used the Campbell Scientific CR9000 software system, which meets all of these requirements.

3.3. Data Acquisition System Identification

The following sections describe in greater detail the system components mentioned in the previous sections including cost of implementation.

3.3.1 Microcomputer System

There were three different design methodologies considered for the data acquisition system. The first methodology would utilize a compact and ruggedized PC module, without keyboard or display, supporting a Windows-based DAS product such as

LabView™. The second approach would use a non-PC-based single board computer module. Finally, we investigated the Campbell Scientific line of DAS units.

The Campbell CR9000 data logger provided an ideal solution for preliminary development. The data logger is a self-contained microcomputer with slots for up to 9 peripheral modules. Available peripheral modules include 0 to 5V and 0 to 50V analog input modules, a PCMCIA expansion module with serial data communication capability, an Analog Output Module, and a Counter Module with Digital I/O. The CR9000 DAS communicates with a host PC over a standard 9-pin RS-232 port. A PC-based application is provided as part of the data logger software package. This application is capable of generating programs for the data logger that controls the data acquisition process. It downloads the program to the data logger's memory and initiates data acquisition. The host application can also display the acquired data in several graphical forms. Based upon the requirements stated in the previous section, we identified hardware modules and software. The Campbell Scientific was run directly from the engine starting battery. Sensors were powered from a small 5 V supply. This supply was selected after the parameters to be implemented were determined. Figure 3-5 provides the hardware selected for the data acquisition system. Figure 3-6 provides the physical and electrical power requirements for the system listed below.

Item	Description	Quantity	Cost
CR9000	Data logger with Software	1	$8,400
CR9050	Analog Input(0 to 5V)	1	$750
CR9055	Analog Input(0 to 50V)	1	$950
CR9060	Excitation Module	1	$1,050
CR9070	Digital Input Module	1	$950
TL925	RS422 to RS232 Converter	1	$520
	Total		**$12,620**

Figure 3-5: Campbell CR9000 Data Logger Hardware Selections

Specifications	
Supply Voltage	12 VDC
Supply Current	2 A
Physical Characteristics	
Length	16 in.
Height	5 in.
Width	10 in.
Availability	
Lead Time	2 weeks

Figure 3-6: Data Logger Hardware Specifications

3.3.2 Radio Frequency (RF) Data Link

The Advantech ADAM-4550 modem met or exceeded the requirements stated in the previous section. The RF Data Link consisted of two radio modems and an antenna for each. One modem was mounted on the MEP-804A. The second was mounted at the host site. The ADAM-4550 unit is a 2.4 GHz radio modem that was connected directly to the DAS and host PC RS-232 DB-9 connectors. The pair of modems thus provided a data channel equivalent to a hard-wired 9-pin RS-232 cable link between these two devices. This equivalence was required to enable use of the software that is packaged with the Campbell Scientific data logger. Each modem was supplied with an antenna so no matching or calibration was required. Diagnostic software was also included for measuring the radio link. Expected range specified by the modem manufacturer is 550 feet under open site conditions. Figure 3-7 provides the hardware cost of the RF data link. Figure 3-8 provides the detailed specification of the RF modules.

Item	Description	Quantity	Cost
ADAM-4550	2.4 GHz RF Modem	2	$1,590

Figure 3-7: RF Hardware Selection

Specifications	
Supply Voltage	12 VDC
Supply Power	100 mW
Modulation	Direct sequence spread spectrum
Band	2.45 GHz nominal
Physical Characteristics	
Length	6 in.
Height	2 in.
Width	3 in.
Availability	
Lead Time	1 week

Figure 3-8: RF Module Specification

3.3.3 Data Acquisition Software

The Campbell Scientific DAS provided a built-in software operating system. However, user interaction with this operating system was not required. As mentioned in Section 3.3.1, the Campbell CR9000 DAS was packaged with PC-based software that allowed user application program generation. Data acquisition programs were configured easily via a graphical user interface with this built-in program generator.

4. ELECTRICAL SPECIFICATION

The electrical specification provides a detailed list of the hardware that was used for the implementation together with the power requirements, the wiring diagrams, and the host PC requirements for the system. The requirements are based upon the 13-parameter system described in CDRL A001[3] and selected by the Air Force Research Laboratory (AFRL) in Captain R. Cardona's letter of 8/13/1999.[4]

4.1. Hardware Requirements

The hardware requirements, shown in Figure 2-1 provide a list of the hardware that was installed to provide the basic 13-parameter system. It includes the DAS hardware, sensors, and radio frequency (RF) link.

Item	Vendor	Part Number	Description	Quantity
1	Campbell Scientific	CR9000	Data Logger	1
2	Campbell Scientific	CR9050	5V Input Module	1
3	Campbell Scientific	CR9055	50V Input Module	1
4	Campbell Scientific	CR9060	Excitation Module	1
5	Campbell Scientific	CR9070	Digital Input Module	1
6	Campbell Scientific	TL925	RS485 to RS 232 Converter	1
7	Advantech	ADAM-4550	2.4GHz RF Modem	2
8	Kavlico	OD-604-7004	Oil Quality Sensor	1
9	Kavlico	P165-100G-E1A	100 PSI Pressure	2
10	Gems	XM-800-51965	Fluid Level	1
11	Kavlico	P-356-5D-E1A	5 PSI Pressure	1
12	Omron	E3T-SR11	Optical Position	1
13	Ohio Semitronics	OSI 3VT-120A	Voltage Transducer	1
14	Vaisala	PTB100A	Barometric Pressure	1
15	Omega	TCJNPTU72	Temperature	1
16	Axiomatic Technologies	TCA-C-J-WG6-N040C-P0085C-01-00	Thermocouple Amplifier	1
17			Resistive Divider	1
18			Misc. Wiring	1
19			Misc. Hardware	1

Figure 4-1: Hardware Requirements

4.2. Power Requirements

The power requirements table of Figure 4-2 lists the current, voltage, and power required to run the DAS. Power was provided from the engine battery when the engine was not operating. The alternator provided power when the engine was running. Figure 2-2 lists all of the power requirements.

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[3] Delivery Order 0007 Aerospace Ground Equipment (AGE) Data Acquisition Design Study and Recommendations (CDRL No. A001), Report to Air Force Research Laboratory, Sustainment Logistics Branch, Wright-Patterson Air Force Base, August 13, 1999.

[4] Letter from Capt. R. Cardona, AFRL, dated August 13, 1999, received by D. Hablanian, Arthur D. Little.

Item	Part Number	Description	Current, Amps	Power, Watts
1	CR9000	Data Logger	2.00@12V	24
2	ADAM-4550	2.4 GHz RF Modem	0.012@12V	.144
3	OD-604-7004	Oil Quality Sensor	0.010@5V	.05
4	P165-100G-E1A	100 PSI Pressure	0.005@5V	.025
5	XM-800-51965	Fluid Level	0.020@12V	.24
6	P356-5D-E1A	5 PSI Pressure	0.005@5V	.025
7	EST-SR11	Optical Position	0.050@12V	.60
8	OSI 3VT-120A	Voltage Transducer	0	0
9	PTB100A	Barometric Pressure	0.004@12V	.048
10	TCJNPTU72	Temperature	0	0
11	CUSTOM	Resistive Divide / Optoisolator	0.020@12V	.24
		Total Power		**25.4**

Figure 4-2: Data Acquisition System Power Requirements

The DAS drew approximately 1.3 amperes from the 24V engine battery. The design was not intended for continuous operation when the generator set is not running. Monitoring was performed during engine startup and when the generator set was in operation.

4.3. Host PC Requirements

The AFRL provided a computer for system testing at WPAFB, OH. The PC provided met or exceeded the following minimum requirements:

- IBM PC Compatible w/ Intel Pentium processor (166 MHz)
- 1 RS 232 Serial Communications Port up to 9600 Baud
- 10 Megabytes free hard drive space for program installation
- Windows™ 95/NT operating system installed
- 16 Megabytes of RAM

5. SOFTWARE SPECIFICATION

The software specification defined the sampling and storage requirements of each sensor.

5.1. Data Logger Specifications

The requirements section lists all relevant requirements of the application, such the language, development tools and the requirements of the application. Figure 5-1 lists the requirements of the software development tools.

Language	The application was written in CR-Basic, supplied with the CR9000 data logger.
Development Tools	The CR9000 software provided program generation, program editing, and download facilities. These were the only development tools used. All tools were provided to the AFRL for future use.

Figure 5-1: Development Tools

The Campbell Scientific CR9000 software provided the key software components:

- Serial communications link
- Sampling configuration
- Interrupt configuration with pre/post store
- Data storage scheduling

5.2. Storage/Sampling Requirements

This section describes the sampling rate for each parameter as well as any manipulation that will be performed to better present the data to the user.

Sensors will be sampled at one of four rates. Figure 5-2 shows the rate each parameter will be sampled, the interval that data will be retrieved by the host PC, the estimated memory requirements to save the data, and the size of the data table that will be generated. The sampling time was based upon the rate at which parameters are expected to change. Parameters that are expected to change rapidly are sampled more often. An interval of 30 hrs was used as the interval of collection. It is expected that data would be collected daily. The 30-hr estimate provides a cushion for memory requirements. The memory requirements are based upon the data size (4 bytes) multiplied by the number of samples in the collection interval provides the memory requirement for a given parameter. The aggregate memory requirement is the sum of all the parameter memory requirements. The final column provides a means to estimate the time required for data collection.

The data from the sensors is obtained in raw measurement form. The raw sensor data will be manipulated to provide meaningful data (e.g. psi instead of millivolts for pressure measurement). Figure 5-3 shows the manipulation that will be performed as well as the units of measure for each parameter.

Sensors	Sample Storage	Size of Sampling Window	Maximum memory for raw data storage (bytes)	Total output table size (bytes)
7) Oil quality 8) Coolant level	1x per 6 hours	30 hours	40	1,270
12) Fuel quantity 13) Coolant temperature 14) Battery voltage 15) Generator voltage 16) Generator current 17) Generator frequency 18) Generator percent power 19) Barometric pressure 20) Inlet air temperature	6x per hour	30 hours	6,480	7,710
2) Oil pressure	60x per hour	30 hours	7,200	8,430
Engine misfire detector, which provides two signals: 3) Exhaust manifold pressure 4) Crankshaft position	1 kHz	30-1 second "snapshots" of 1,000 samples*	240,000	241,230
Estimate of total memory required (bytes):				250,210

Figure 5-2: Memory Requirements for Datalogging

*It was previously reported that only one snapshot of engine misfire sensor data would be saved in a 30-hour interval. This capture rate was increased to one snapshot per hour to enable better correlation of misfiring with changes in operating conditions. The additional data storage space was available and no additional memory was required.

Sensors	Conversion Routine	Output
Oil Quality	(Data – 0.5) x 0.25	0 to 1
Coolant Level	Data x 0.083333	0 to 1 (1 = Full)
Fuel Quantity	(5-Data) x 0.344827	0 to 1 (1 = Full)
Coolant Temperature	((Data – 5.5) x 13.33) + 100	100 to 240 °C
Battery Voltage	Direct Reading	0 to 24 Volts
Generator Voltage	Data x 30	0 to 150 Volts AC
Generator Current	Integral of Current(50K Reading)	Amps
Generator Frequency	49+0.6 x Data	0 to 60 Hz
Generator Percent Power	Data * 1.5	0 to 133%
Barometric Pressure	(Data x 52) + 800	800 to 1060 hPa
Temperature	(Data x 25) – 40	-40 °C to 85 °C
Oil Pressure	(Data – 0.5) x 25	0 to 100 PSI
Exhaust Manifold Pressure	(Data – 0.5) x 1.25	0 to 5 PSI
Crankshaft Position	Direct Reading	0 to 5 Volts

Figure 5-3: Data Conversion Factors

** Must run genset with a load bank to determine this data.

6. IMPLEMENTATION

This section describes installation of the DAS and sensors. The implementation was performed according to the hardware and software detailed specifications, which were initially provided in CDRL A002[5]. The revised final draft is provided in conjunction with this report. After completion of the specification and subsequent approval by the AFRL, ADL proceeded with the remainder of the implementation phase. Detailed instructions of the implementation are provided in Appendix D. This section provides an overview of the installation of new sensors and DAS.

The recommended test bed consisted of the full DAS with the 13 most relevant parameters. Figure 6-1 provides a block diagram of the MEP-804A generator set with the sensors relating to the relevant systems. All sensors are connected to the data acquisition system.

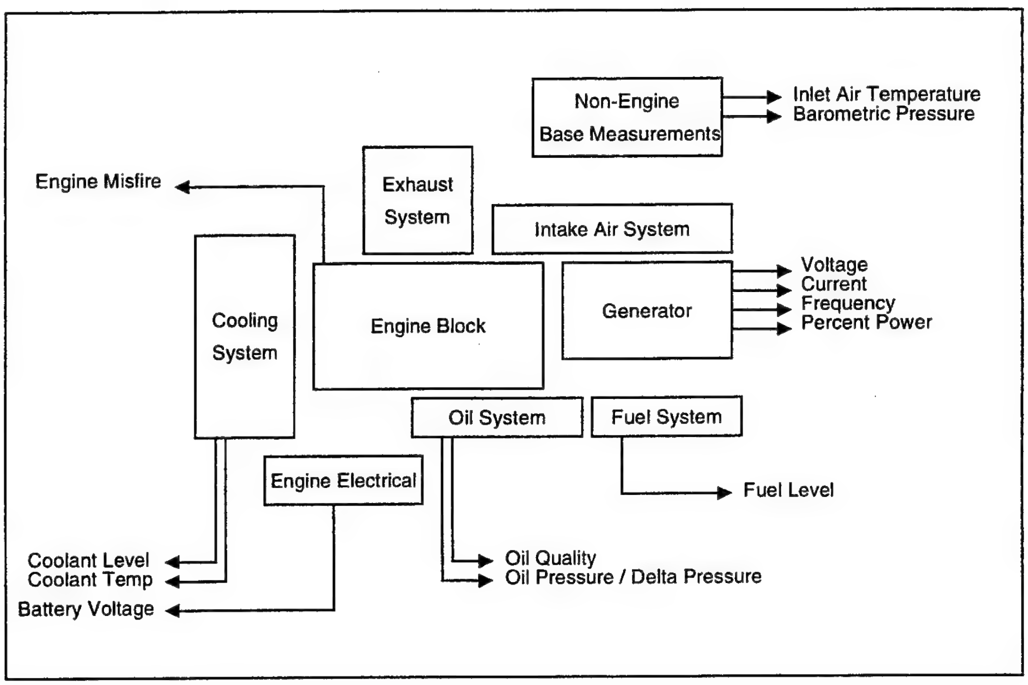


Figure 6-1: Block Diagram for Recommended Generator Set Sensors (13 Parameters)

[5] D. Hablanian, et al, "Detailed Design Specification and System Test Plan", September 13, 1999.

The procurement cost of the sensors is shown in Figure 6-2.

Item	Part Number	Description	Unit Cost	Quantity	Cost
1	CR9000	Data Logger	$8,400	1	$8,400
2	CR9050	5V Input Module	$750	1	$750
3	CR9055	50V Input Module	$950	1	$950
4	CR9060	Excitation Module	$1,050	1	$1,050
5	CR9070	Digital Input Module	$950	1	$950
6	TL925	RS485 to RS232 Converter	$520	1	$520
7	ADAM-4550	2.4GHz RF Modem	$795	2	$1,590
8	OD-604-7004	Oil Quality Sensor	$500	1	$500
10	P165-100G-E1A	100 PSI Pressure	$199	2	$398
13	XM-800-51965	Fluid Level	$587	1	$587
14	P356-5D-E1A	5 PSI Pressure	$274	1	$274
16	EST-SR11	Optical Position	$104	1	$104
17	OSI 3VT-120A	Voltage Transducer	$230	1	$230
18	PTB100A	Barometric Pressure	$795	1	$795
19	TCJNPTU72	Temperature	$35	1	$35
20		Resistive Divider	$10	1	$10
21		Misc Wiring	$500	1	$500
22		Misc Hardware	$500	1	$500
				Total	$18,143

Figure 6-2: Bill of Materials for Recommended Generator Set Sensors (13 Parameters)

6.1. Oil Quality Sensor

The oil quality sensor was mounted on the oil pan on the right hand side of the engine. Due to the location of the sensor a photo was not possible. Mounting required removal of the oil pan. The pan was drilled and fitted with a threaded braze-on bushing. The sensor was mounted into the braze-on bushing. Wiring was routed from the sensor around the front of the engine to the data acquisition system.

6.2. Oil Pressure/Differential Pressure

Differential oil pressure sensing required two sensors. Pressures at each side of the oil filter were measured. Engine oil pressure was measured at the outlet side of the filter. The existing connection was used to measure the outlet pressure. Only the addition of T-fitting was required. The fitting was added to the oil pressure outlet and the new sensor was mounted to the T fitting. The black arrow indicates the sensor (Figure 6-3). Generally, there is no existing pick-off for filter inlet pressure. Installation of the inlet sensor was achieved by removing the filter mount and drilling and threading a hole into the mount. The mount was analyzed to determine oil flow in order to determine the best place to drill the hole. Care was taken to avoid drilling in an area that would weaken the mount (Figure 6-4).

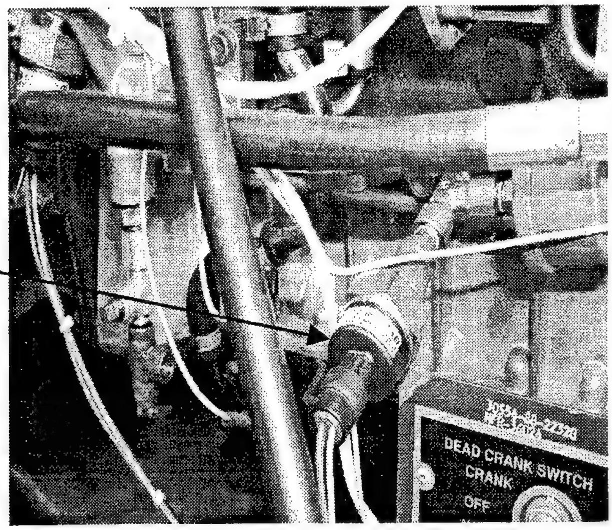


Figure 6-3: Oil Inlet Sensor

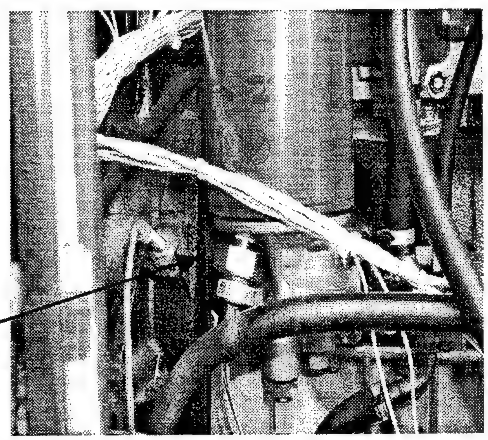


Figure 6-4: Oil Outlet Sensor

6.3. Coolant Level

The coolant level sensor was mounted to the top of the coolant reservoir cap. The cap was removed and three holes were drilled. Three holes were also drilled and threaded into the flange on the sensor itself. The sensor was placed onto the top of the cap. Screws were used to fasten the cap to the sensor and then it was replaced on reservoir bottle (Figure 6-5).

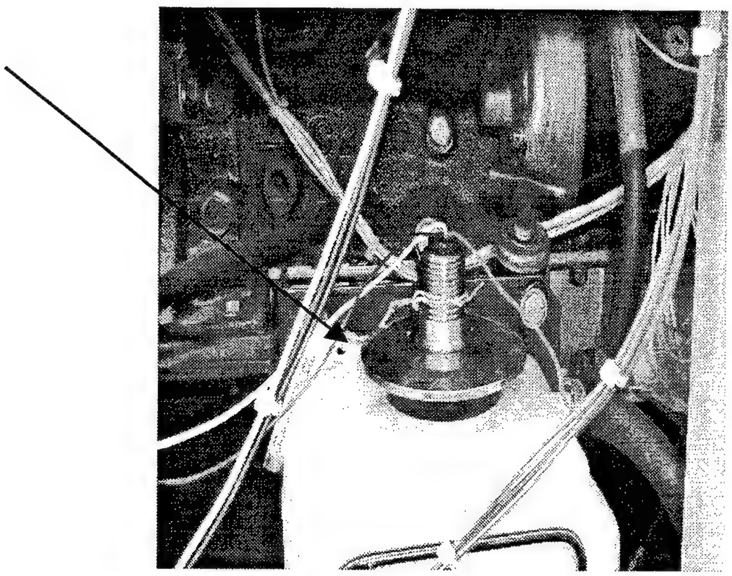


Figure 6-5: Coolant Level Sensor and Bottle

6.4 Engine Misfire Detection

Engine misfire detection required three sensors. The percent power indication was already provided by an existing power transducer. New sensors were added to obtain crankshaft position and exhaust gas pressure. The crankshaft position was obtained using an optical sensor. A bracket was mounted on the crankshaft pulley. The leading edge was aligned with the 0-degree mark of the engine timing line. The optical sensor was an infrared transmitter and detector. The detector was adjusted to be approximately 0.8 in. from the bracket. The bracket reflected the signal from the transmitter that was detected by the receiver once per revolution with the start of the pulse indicating 0-degrees (Figure 6-6). This is used as a timing reference. Exhaust pressure was sensed using a low-pressure transducer mounted to the exhaust system. A small tube was welded onto the exhaust manifold. The sensor was screwed into the end of the tube (Figure 6-7). This provided the pressure output. These three sensors provided means to determine misfire by future host analysis software.

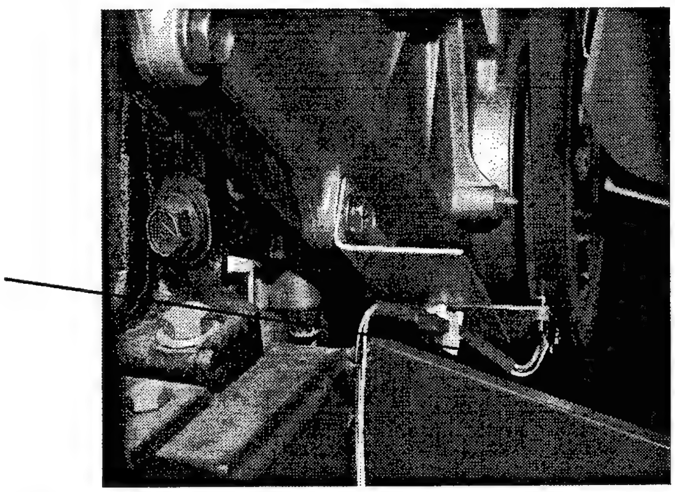


Figure 6-6: Optical Sensor for Crankshaft Position

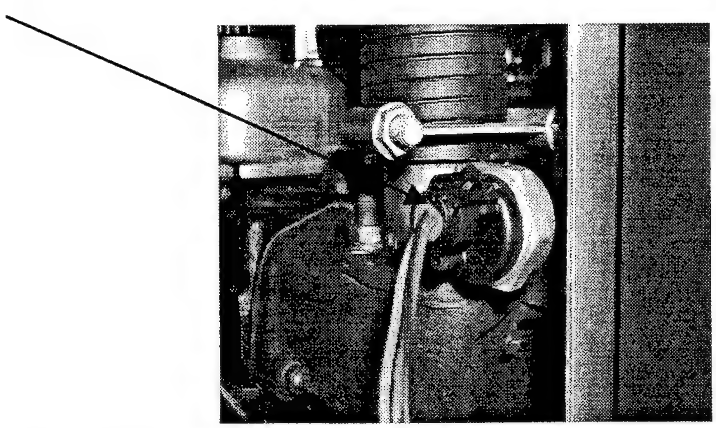


Figure 6-7: Exhaust Gas Pressure Sensor

6.5 Temperature Sensor

A thermocouple was used to measure inlet temperature. To achieve the best measurement of inlet temperature the sensor was located directly in front of the opening to the air filter. A bracket was mounted to the generator. The thermocouple was mounted to the bracket using a clamp. Due to the location of the thermocouple no photo is available.

6.6 Voltage Transducer

The three-phase voltage transducer was used to measure the voltage output of the generator. The transducer was mounted inside of the generator electronics bay behind the control panel (Figure 6-8). Resistors were mounted to the transducer to provide a voltage output in the 0-5V range.

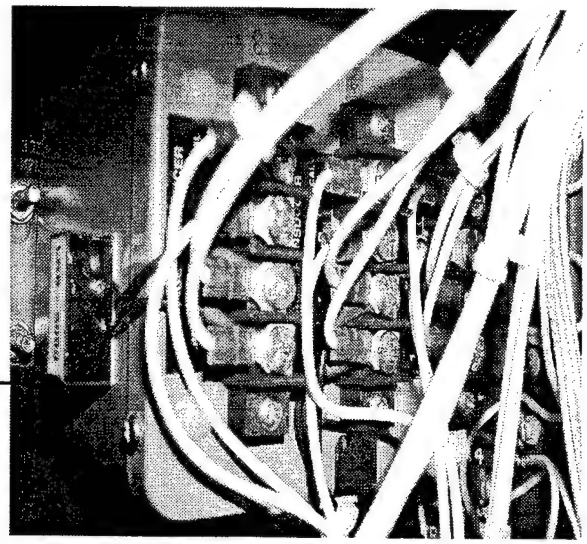


Figure 6-8: Voltage Transducer

6.7 Barometric Pressure

There were no specific installation requirements for the barometric pressure sensor and it was mounted on an accessory panel along with the power supply and RF components (Figure 6-10f).

6.8 Data Acquisition System (DAS)

There were several components associated with the data acquisition system. They were the Campbell Scientific DAS, the RF modem, and the power supply components. The DAS was mounted inside the door on the right hand side of the engine. Two rails were mounted vertically from the top of the door opening to the bottom. The DAS was secured to these rails. It was set far enough from the engine to prevent damage from heat but still allow the door to be securely closed. All sensor wiring came to this area. Grounding and power bus blocks were attached to the rails for power distribution purposes (Figure 6-9). There were two batteries mounted in the DAS. Main power was provided from the 24V generator batteries and charging system. The internal DAS batteries were charged when this engine supply was operational. When the engine

battery charge was low and the charging system was not operational, DAS power was provided from internal batteries. 12V and 5V supplies were required for the sensor and additional circuits to control when the 24V or internal batteries were used. These components consisted of a 24V to 12V DC-DC converter (Figure 6-10d), a 12V-5V DC-DC converter (Figure 6-10e), and a switching relay (Figure 6-10c). These components were mounted to the accessory mounting panel (Figure 6-10).

The RF and communications circuits were mounted to the accessory mounting panel as well. They consisted of the RF modem (Figure 6-10a) itself which was used to convert the data to a RF signal and a data converter (Figure 6-10b) that converted signals between the modem and the DAS. The mounting panel was fixed to the door opposite the data logger to minimize the communications wiring and to provide access to the components.

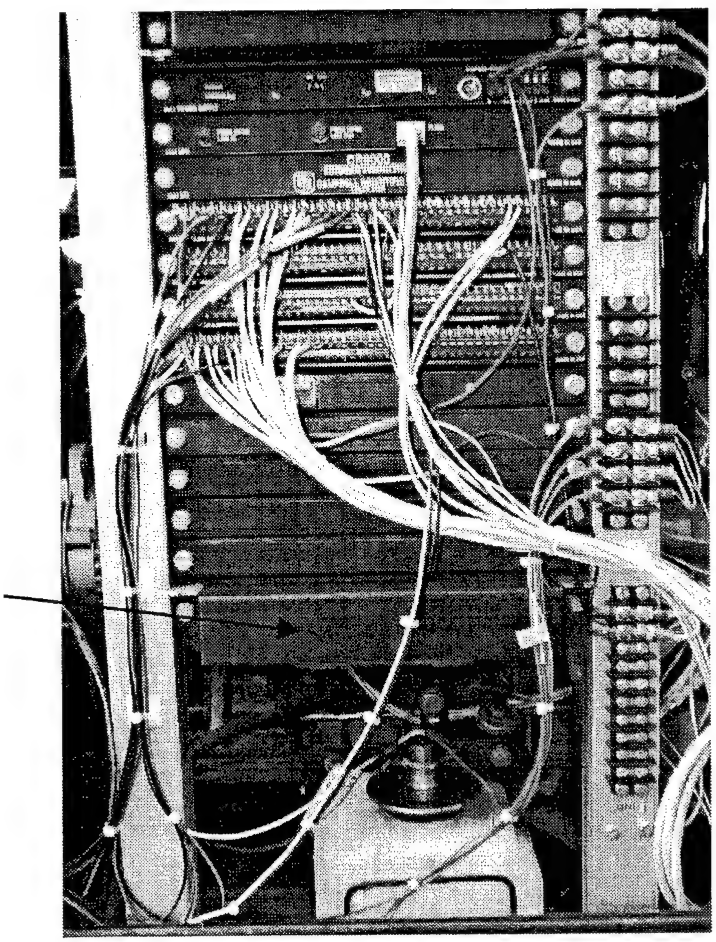


Figure 6-9: Campbell Scientific Data Acquisition System Installed on MEP-804A Genset

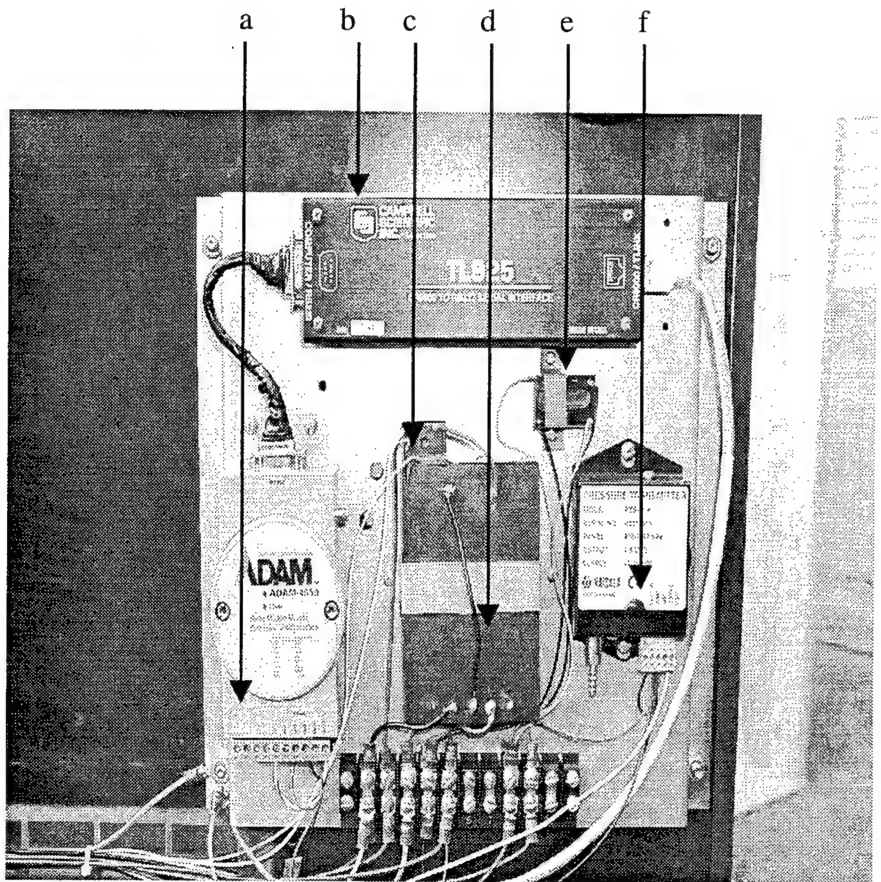


Figure 6-10: RF Modem and Power Supply

Components:

a.) RF Modem
b.) Data Converter
c.) Switching relay
d.) 24V to 12V DC-DC Converter
e.) 12V-5V DC-DC Converter
f.) Power Supply and RF Components

7. TEST RESULTS AND ANALYSIS

Testing was performed in three phases. First, bench-top tests were performed to calibrate the sensors. Second, a system test was performed successfully on November 8, 1999 at ADL. Finally, a system test was performed successfully at AFRL on December 14, 1999.

Several tests were performed to verify the operational state of the DAS as well as to verify and calibrate the new sensors. This section provides the results of those tests. Detailed procedures that explain the actual tests are provided in Appendix C.

7.1 BENCH TEST RESULTS

Bench tests were performed to obtain calibration curves for the data acquisition software. The results and analysis that follow explain how the information would be used.

7.1.1 Oil Quality Sensor

The oil quality sensor was the most important sensor to test prior to installation. The data obtained by these tests provided a baseline to begin an understanding of how the information would be interpreted in future work. The oil quality was tested by using new and used oil samples to provide rough estimates of what one might observe for various grades of uncontaminated oil. It is very important to remember that a detailed analysis was beyond the scope of Delivery Order 0007, and therefore this test, was performed only to obtain example data. The results of this test (Figure 7-1) show that new oil gives an output of about 0.94V and for older oil the voltage increases to 1.36V. The used oil had about 26 hours of service so there was still a significant amount of usage time remaining.

Condition	Output (Volts)
New Oil	0.94V
Used Oil	1.36V

Figure 7-1: Oil Quality Oil Comparison

A second test was run to determine effects of coolant on the output of the sensor. The results are displayed in Figures 7-2 and 7-3. As coolant was added to the oil, the voltage increased to full scale. This demonstrated that the sensor can detect conductive contaminants such as coolant.

50% Glycol (mL)	Output (Volts)
2.5	0.95
5.0	0.98
7.5	1.02
10.0	1.07
12.5	1.19
15.0	1.29
17.5	1.35
20.0	1.61
22.5	2.07
25.0	2.45
27.5	2.78
30.0	3.27
32.5	3.84
35.0	4.36

Figure 7-2: Coolant Additive Effects on Oil Quality Output

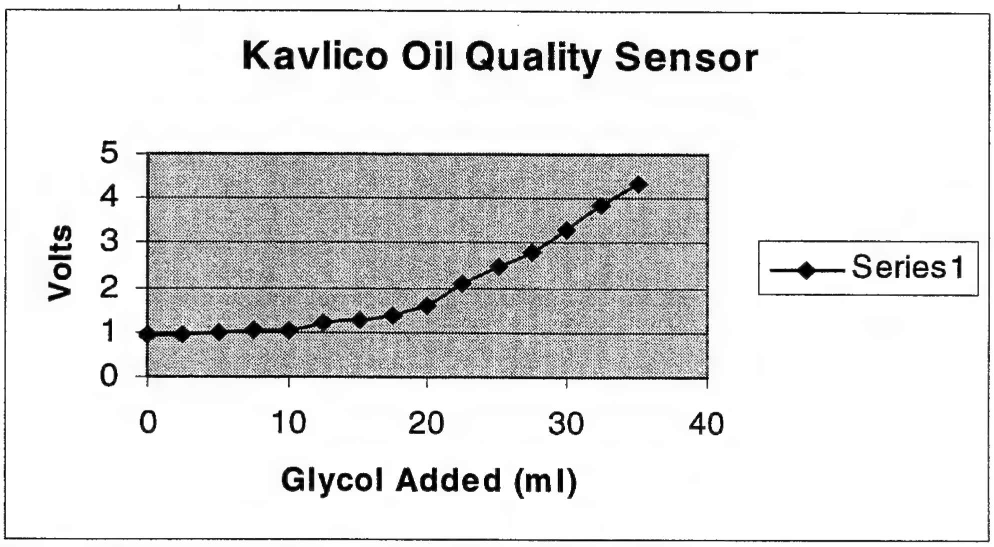


Figure 7-3: Glycol Level (ml) vs. Oil Quality Output (Volts)

7.1.2 Coolant Level Sensor

The coolant level sensor was tested to determine the linearity of its response. The data and graph (Figures 7-4 and 7-5) shows that after the coolant reached the starting level of measurement it had a linear behavior resulting in very simple conversion by software to a measure of coolant level.

Coolant Level (in.)	Output (Volts)
0.0	0.00027
0.5	0.00027
1.0	0.00027
1.5	0.00027
2.0	0.4835
2.5	1.7147
3.0	2.9457
3.5	4.178
4.0	5.409
4.5	6.639
5.0	7.870
5.5	9.103
6.0	10.335
6.5	11.568

Figure 7-4: Coolant Level Sensor Output

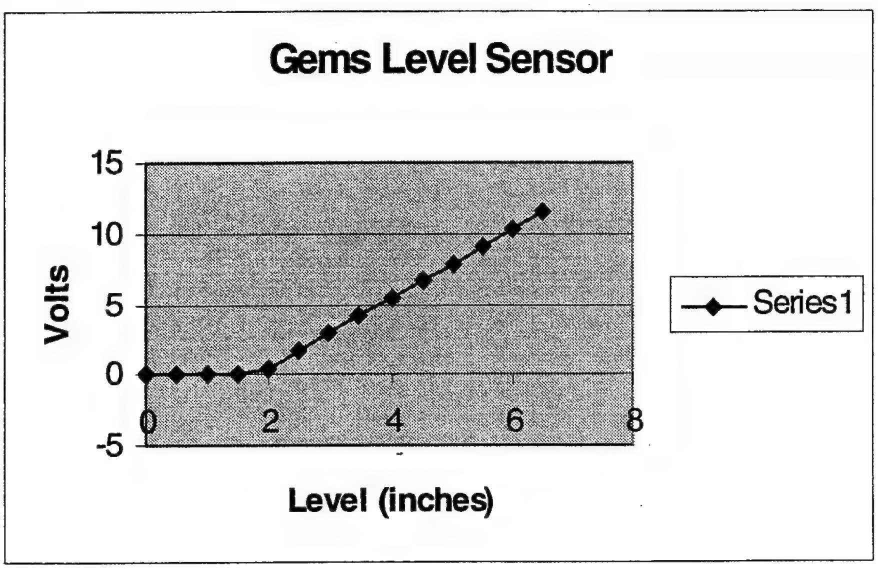


Figure 7-5: Coolant Level (in.) vs. Sensor Output (Volts)

7.1.3 Kavlico Pressure Sensor P165-100G-E1A

The Kavlico sensors were all tested to verify their output capability prior to installation. The P165-100G sensor was used for measuring both the inlet and outlet oil pressures. Both units were tested for linearity and operation to their upper limit. Figures 7-6 and 7-7 show that the sensor performed per specification over its entire range of operation. The sensors were tested using a calibrated pressure source and measuring the output with a voltage meter.

Pressure (psi)	Output (Volts)
0	0.50
5	0.72
10	0.92
15	1.13
20	1.32
25	1.52
30	1.72
35	1.92
40	2.12
45	2.32
50	3.51
55	2.72
60	2.92
65	3.11
70	3.32
75	3.52
80	3.71
85	3.91
90	4.12
95	4.32
100	4.52

Figure 7-6: P165-100G Pressure Output

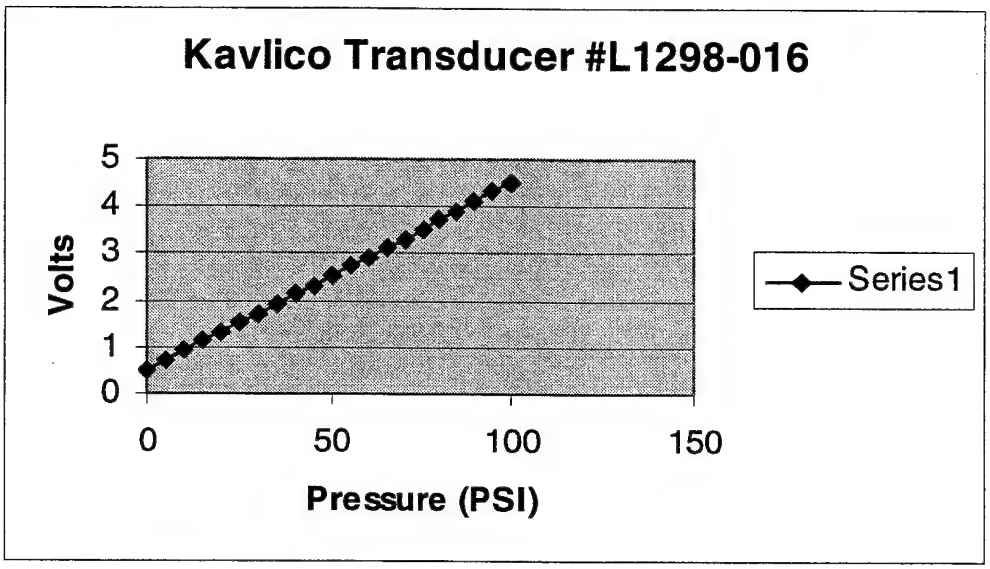


Figure 7-7: Pressure (psi) vs. P165-100 Sensor Output (Volts)

7.1.4 Kavlico Differential Pressure Transducer P356-5d-E1a1

The differential pressure transducer was also tested for operational performance and linearity over its entire range. Testing was performed by applying a known pressure over the operational range and measuring the output of the sensor. Figures 7-8 and 7-9 show that the sensor operated properly with excellent linearity.

Pressure (PSI)	Output (Volts)
0.0	0.50
0.5	0.96
1.0	1.36
1.5	1.82
2.0	2.18
2.5	2.60
3.0	3.04
3.5	3.41
4.0	3.82
4.5	4.23
5.0	4.60

Figure 7-8: P356-5D Pressure Output

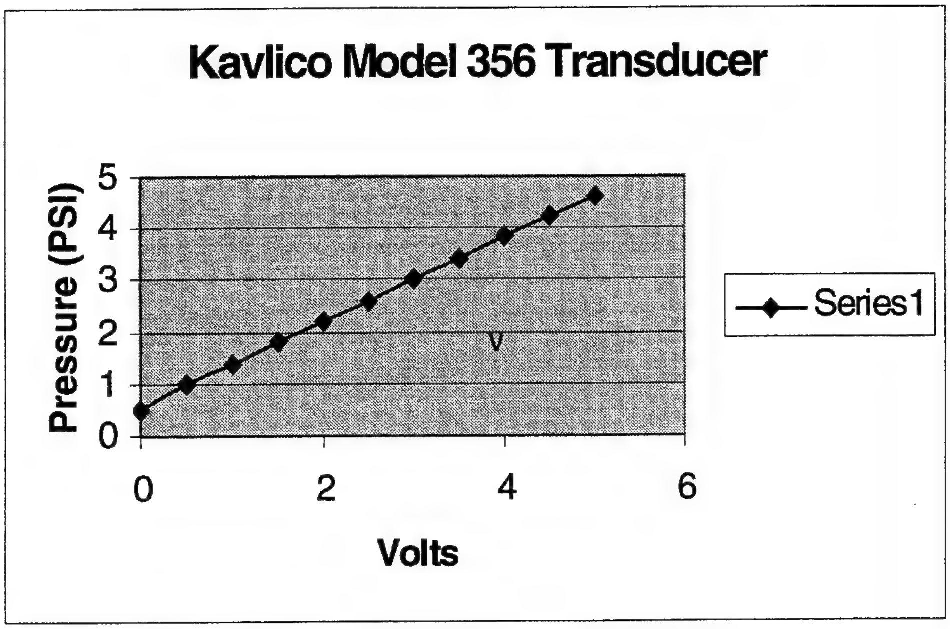


Figure 7-9: Pressure (PSI) vs. P356-5D Sensor Output (Volts)

7.2 System Tests

System tests were performed at both Arthur D. Little and at Wright Patterson Air Force Base. This section provides a description of the both tests as well as photos of the tests at WPAFB.

7.2.1 System Test at Arthur D. Little

Systems Tests at ADL were conducted on November 8, 1999. Captain Rudy Cardona and Captain Kevin O'Conner of AFRL were present. A laptop PC used as a representative host computer was placed approximately 60 ft from building 42 at ADL. The generator was connected to a load bank located in building 42. The generator was started and the load bank was adjusted for 50% load. The PC-9000 software was running on the laptop. Each of the sensors was demonstrated with the PC-9000 software. The

system tests were performed in accordance with those specified in Appendix C. All system parameters operated as specified.

7.2.2 System Tests at WPAFB

The system was tested at WPAFB building 190 on December 14, 1999. A load bank was located in building 190. The generator set was connected to the load bank. The generator was located approximately 100 ft from the host modem located outside building 190. The host modem serial data port was connected via a 60 ft cable to a laptop PC in Conference Room 1.

The generator modem had to be reconfigured due to the angle of the generator and the location of the host modem on building 190. To obtain adequate signal strength the generator set modem was mounted on the outside of the access door on the left-hand side of the engine. After this was done, there were no further problems with the system configuration.

The generator was left running for the entire Final Program Review. During the presentation the system was demonstrated for the MASS IPT team and Logistics Sustainment Branch. Once again the system operated as specified. After completion of the operation demonstration a walk through of the system was provided. Below are selected photos from the demonstration.

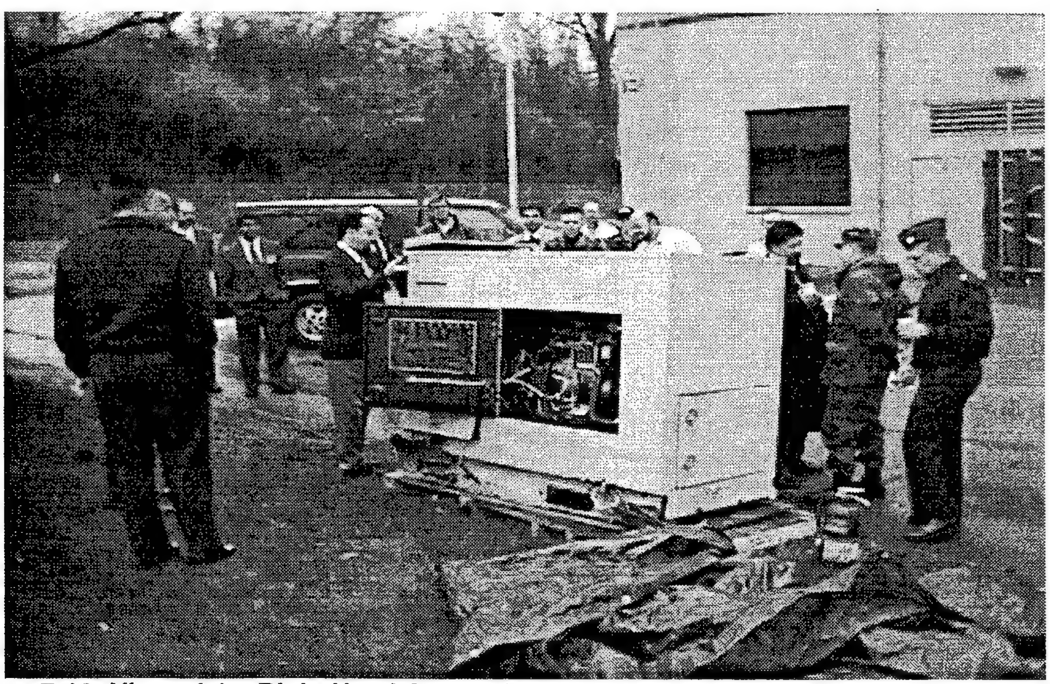


Figure 7-10: View of the Right Hand Access Panel

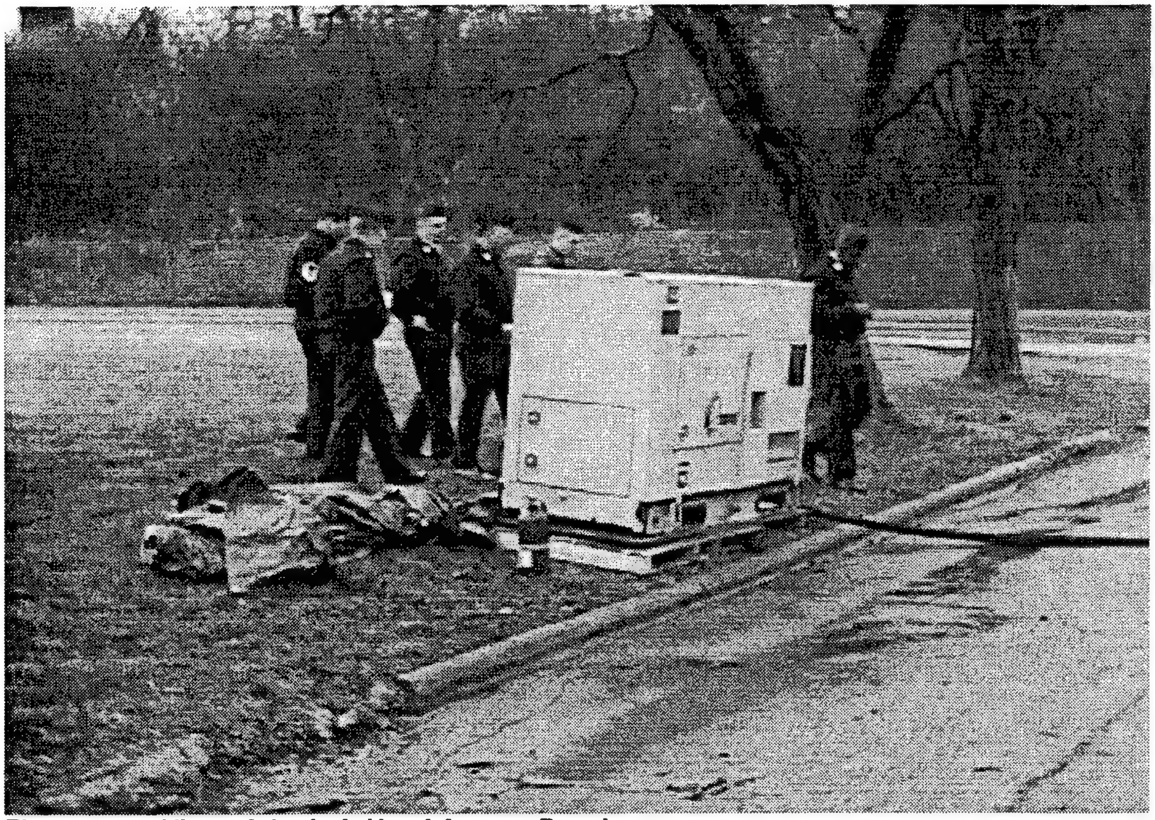


Figure 7-11: View of the Left-Hand Access Panel

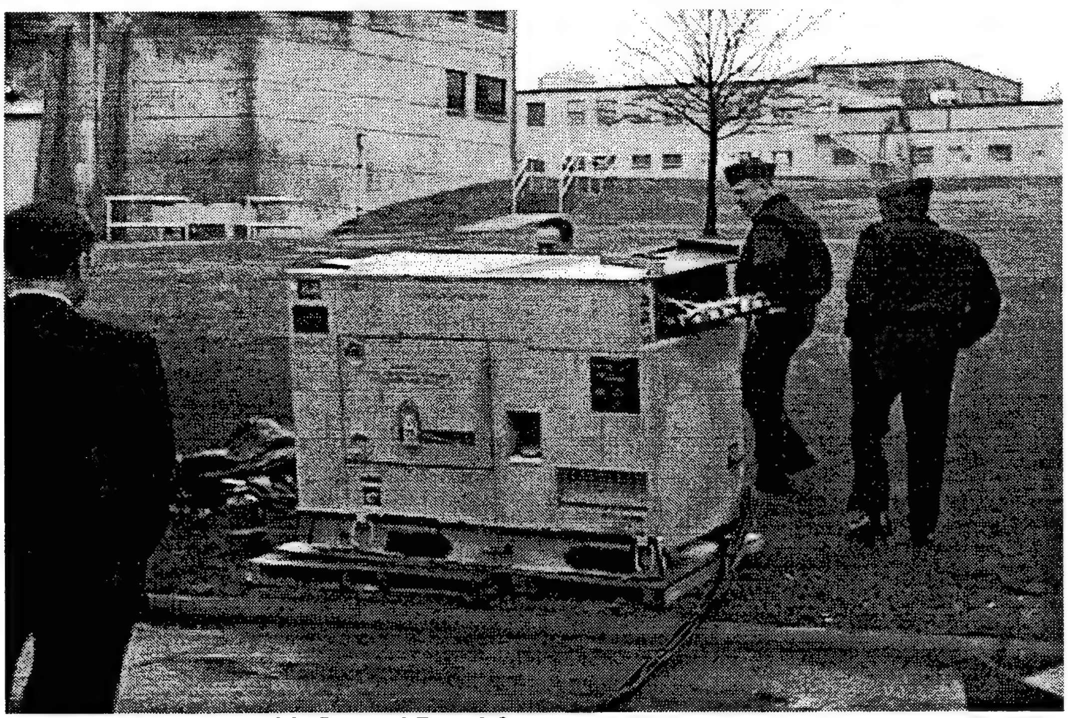


Figure 7-12: Generator with Control Panel Open

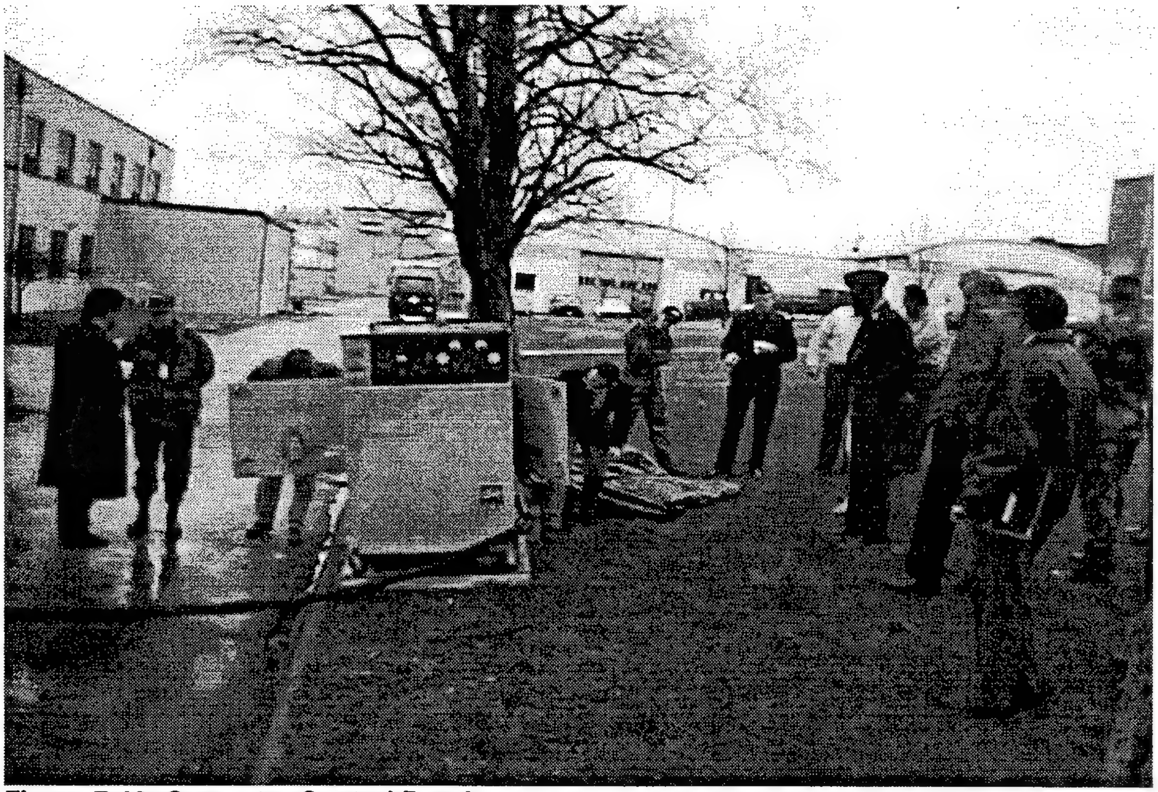


Figure 7-13: Generator Control Panel

8. CONCLUSIONS (PART I)

The project goals for Part I of DO7 were all met as was demonstrated by operation of the instrumentation system to the complete satisfaction of AFRL program management at the Program Review Meeting of December 14, 1999. The generator set was retrofitted with sensors, a DAS unit and radio modem to capture and transmit performance parameter data to a remote host computer. Data provided to this computer could ultimately be used to assess AGE unit state of readiness, predict future maintenance needs or identify reasons for inoperability or substandard performance. During testing and demonstration performance parameter data was successfully captured, transferred via radio link and stored/displayed on a demonstration host computer.

A key lesson-learned as a result of this work is that performance parameter instrumentation can be readily retrofitted to an existing AGE unit without major hardware modifications. An easily configured, highly flexible and expandable general-purpose COTS DAS unit was employed for the demonstration to minimize program cost and accommodate future research needs. However, a much more economical DAS and integrated radio modem or other data exchange mechanism could be purpose-designed/manufactured for AGE retrofits to achieve an affordable solution for high volume deployment. The potential to leverage low cost COTS microelectronic and sensor technology provides confidence that the envisioned automated AGE condition assessment can be achieved in a cost-effective manner.

The retrofitable AGE instrumentation system installed under the DO7 program provides the AFRL with the desired platform for demonstrating and further developing AGE supportability enhancement concepts.

Key accomplishments of Part I of the Delivery Order 0007 program include:

- Instrumentation of engine and generator performance which have promise to provide useful readiness, prognostic and diagnostic information
- Instrumentation of oil quality using an advanced technology sensor
- Identification and use of COTs sensors, DAS and radio link modem components to minimize program risk and to demonstrate a path to affordable deployment of this technology in the future
- Identification of simple and minimally invasive means to install new sensors and utilize existing ones

PART II – WIRELESS DATA ACCESS SYSTEM DESIGN

9. TECHNICAL APPROACH

In the first part of MASS DO7 we demonstrated that performance parameter instrumentation can be retrofitted to an existing AGE genset without major hardware modifications. This demonstrated to AFRL the potential for automatic AGE condition assessment system. To further demonstrate the strength and promise of such a system, AFRL requested ADL to perform work to determine how to take the performance parameter data, perform some preliminary analysis on it, and broadcast it wirelessly to remote clients. Remote users might include:

- Aircraft maintenance technicians
- Logistics officers
- AGE operators
- AGE maintainers

Each potential user class has a unique set of data they must track. The goal was to demonstrate a system that would capture all such data and make it available to remote users wirelessly via a handheld device.

9.1 System Architecture

The system architecture built upon the system developed under DO7. As shown in Figure 9-1, this includes:

1) Data acquisition on the AGE
2) An RF link from the AGE to a data acquisition computer with a Local Area Network (LAN) connection for data storage
3) A demonstration computer with connections to the LAN and the internet
4) Wireless web browsing devices for data display

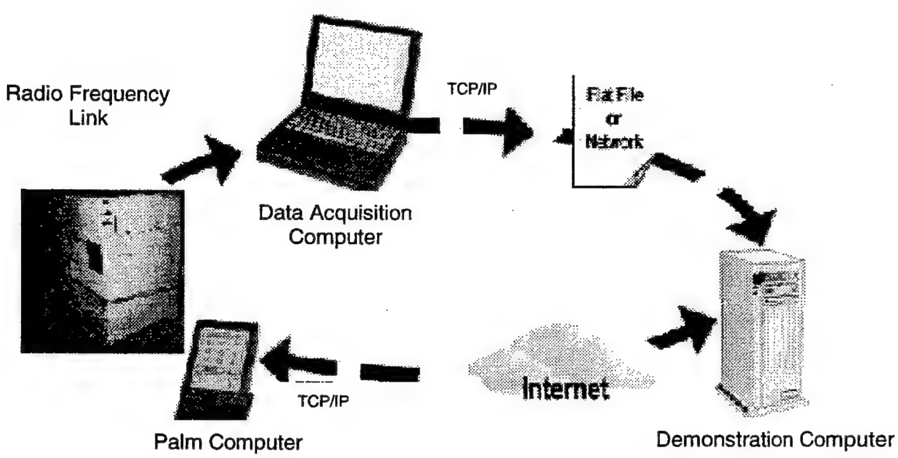


Figure 9-1: System Architecture

We selected a web-based approach for data retrieval in order to leverage "off-the-shelf" methods for data formatting and transmission of information to clients. These include Hypertext Transport Protocol (HTTP) for data transmission and Hypertext Markup Language (HTML) for data formatting thus allowing the application to remain independent of the client used to view the data.

In addition, the system will demonstrated capability to send and receive messages from, to, and between hand-held device users (directly or via an interim server/network), as shown in Figure 9-2 below.

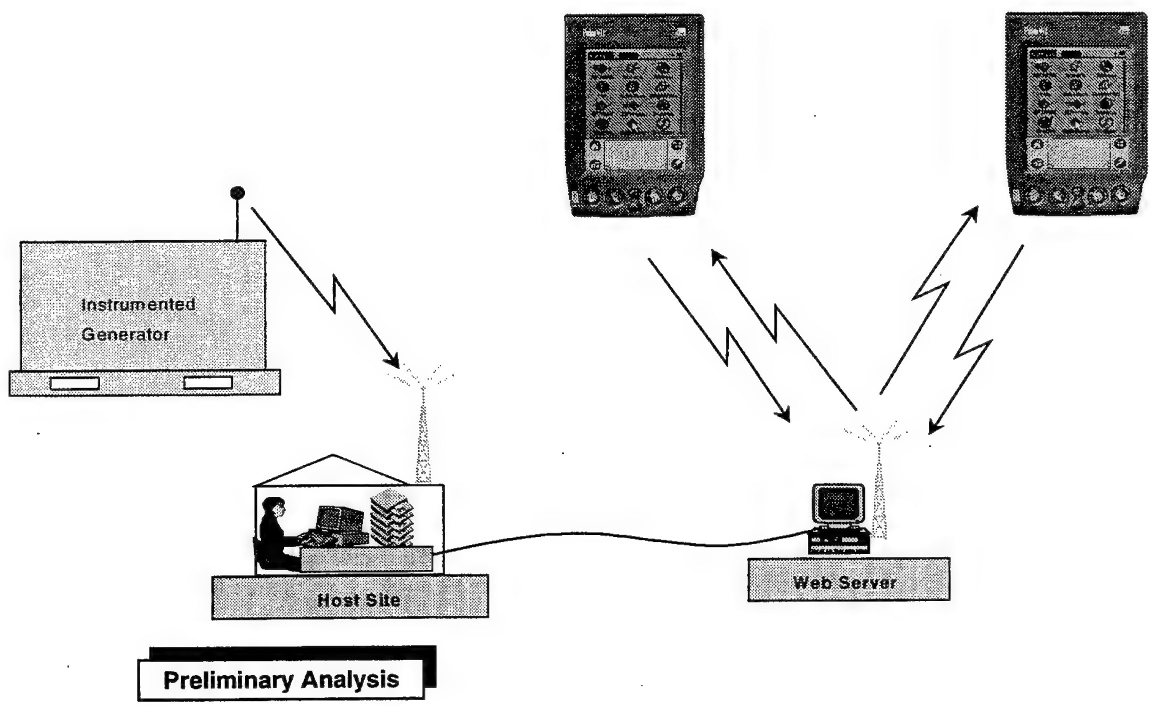


Figure 9-2: System Capability

10. Concept of Operations Document (CONOPS)

Captain Rudy Cardona of AFRL provided Arthur D. Little with a Concept of Operations (CONOPS) to provide a realistic scenario of logistics processes that will support the demonstration of the functional capabilities of this system. The CONOPS was written as a series of time frames to describe the activities of Logistics Group (LG) and Operations Group (OG) personnel during the day as they perform their tasks. Appendix F contains a copy of revision 3.0 of this CONOPS. The intention of this DO7 task was not to demonstrate the entire CONOPS scenario, but to show feasibility.

Key functional items required to meet this CONOPS include:

- The ability for the Equipment Maintenance Squadron's (EMS) Maintenance Supervisor to evaluate the overall state of readiness for each fighter squadron remotely
- The ability for the system to "page" or email an individual when an alert state has occurred (i.e. a critical number of MASS carts are not mission capable)
- The ability for an individual to relay this alert to another
- The ability for an individual to get detailed state of readiness information (i.e. service personnel would need to know which items need repair/replacement)

11. Hardware Selection

The current state-of-the-art in wireless, handheld web access devices was researched with the understanding that this is a proof-of-concept demonstration and that this industry is changing rapidly with new devices that have new capabilities coming to market frequently.

11.1 Hardware Requirements

In order to show proof of concept, the system hardware needed to perform two key functions:

(1) Provide a means for accessing remote data on a server
(2) Provide an alert capability

In addition, the following features were considered important:

(1) Handheld device
(2) Display that is large enough to display AGE data with minimal scrolling
(3) Capable of displaying HTML

11.2 Demonstration Hardware Identification

Devices meeting the two key requirements (while addressing the other needs as well) fell into the following categories:

(a) Personal Digital Assistants (PDAs), such as the Palm devices from Palm, Inc. with integrated or add-on wireless modems.
(b) Two-way Pagers like the Blackberry pager from Research in Motion, Ltd.
(c) Web enabled cellular telephones like the Neopoint 1000 or the PdQ from Kyocera.

The following sections summarize the pertinent capabilities of these devices.

Palm VII

The Palm VII from Palm, Inc. is a PDA with wireless modem integrated into its package. It runs the PalmOS operating system, which has become a strong standard in the PDA industry. It uses the BellSouth Wireless Data Network, has excellent web access via third party micro browsers as well as a mechanism to access specific web sites via efficient, custom designed applications called Palm Query Applications. These enable sites to pass only dynamic data over the wireless connection while the static data stays resident on the Palm device. The main drawback with the Palm VII for DO7 was its lack of some standard method for notifying users when an exceptional condition occurred in the system requiring an alert.

Figure 11-1: Palm VII

Palm V with OmniSky Modem

The Palm V from Palm, Inc. is another PalmOS PDA, except without a wireless modem. The wireless modem in this case is an add-on from Omnisky. It uses the Cellular Digital Packet Data network. It has the same excellent web access as the Palm VII. The improvement over the Palm VII in this application is that OmniSky has implemented a means for an email alert to be delivered to the user via an LED. This is done by providing an automated fifteen minute polling of the subscribed email services. Up to six different email services can be used and they can be any Post Office Protocol (POP) email system.

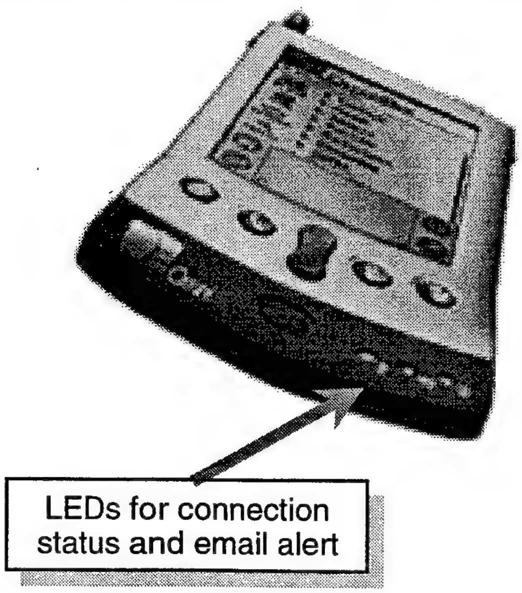


Figure 11-2: Palm V/Modem from OmniSky

Blackberry Pager from RIM

The Blackberry pager from Research In Motion (RIM) is an advanced pager system. It uses the BellSouth Wireless Data Network. It is functionally a two-way text-based paging system. It does all of its data via store-and-forward. This is suitable for email and page messages but not acceptable if near real-time data access is needed as in this application. The version evaluated for this study had a small display.

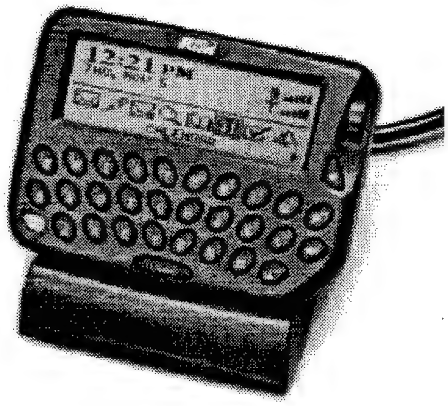


Figure 11-3: Blackberry Pager

Neopoint 1000

The Neopoint 1000 is code-division multiple access (CDMA) cellular telephone. It is currently distributed for use with the Sprint PCS system. It has an integrated PDA with a custom minbrowser for web access. It does not support text-based paging but information could be "pushed" via an automated cellular call together with an email. It has a smaller screen than the Palm PDA's but larger than the Blackberry Pager.

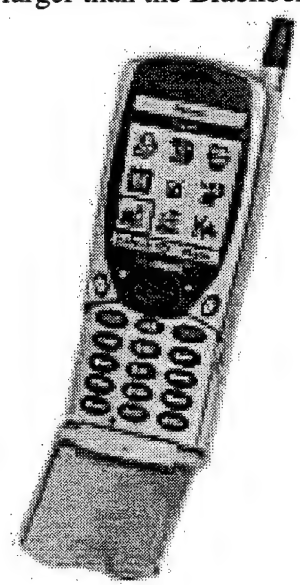


Figure 11-4: Neopoint 1000

pdQ

The pdQ is code-division multiple access (CDMA) cellular telephone with an integrated Palm PDA. It is currently distributed for use by Kyocera (formerly made and distributed by QualComm). It has the same browser capabilities as the Palm VII and Palm V. Like the Neopoint 1000 it does not support paging but functions as a full cellular telephone.

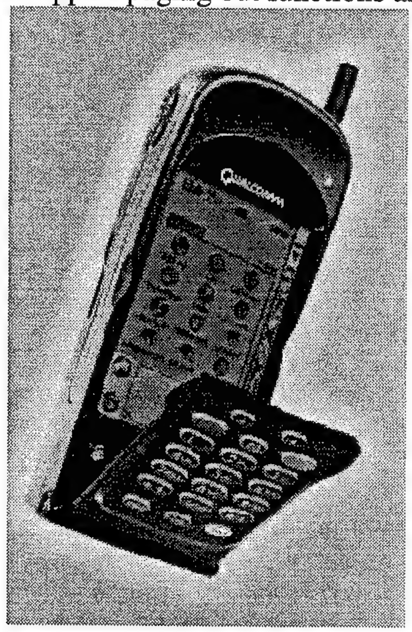


Figure 11-5: PdQ

11.3 Hardware Summary

Figure 11-6 summarizes the features of the devices investigated.

Device	Text Paging	Messaging	Web Server Access	Display Size	Comments
Palm VII		✓	✓	large	
Palm V with OmniSky Modem	✓**	✓	✓	large	** Pushed alerts implemented via fifteen minute polling of email
Blackberry	✓	✓	✓*	small	*Browsing not real time – store-and-forward messaging
Neopoint		✓	✓	medium	
pdQ		✓	✓	large	

Figure 11-6: Hardware Summary

We selected the Palm V with wireless modem from OmniSky as the best fit because of its robust web access, large screen for data display, and email alert capability. The Palm VII was eliminated from consideration because it lacked the email alert function. The other devices had adequate alert functions but limited data access and display capabilities.
It is important to note the hardware selected for the feasibility demonstration is independent of the software implementation. Any of these devices could be used with little change to the implementation.

12. SOFTWARE IMPLEMENTATION

This section provides an overview of the design and implementation of the software system developed to meet the requirements captured from the CONOPS document. The CONOPS describes a situation in which logistics and operations personnel have constant access to key decision-making data. The situation described in the CONOPS does not exist today. We developed the software system to demonstrate the feasibility of such a situation to exist in the near future.

The principal requirement was to demonstrate the ability to distribute diagnostic data captured from the MEP-804A generator to remote PDAs using HTML. After investigating a number of implementation options, we decided upon the Java platform for the implementation of the MASS DO7 demonstration software.

Java offered the following advantages over other implementation options:

(1) Distributed
(2) Object-oriented
(3) Multi-threaded
(4) Network-centric
(5) Standard extensions for web integration

We employed a multi-tiered architecture in which independent software components cooperate to meet system requirements. Figure 12-1 shows the deployment diagram for the system we developed. The diagram describes the configuration of processing resource elements and the mapping of software components onto them. The software components are denoted as rectangles with two small rectangles projected from the side. The section that follows describes each of the software components and how information flows through the system.

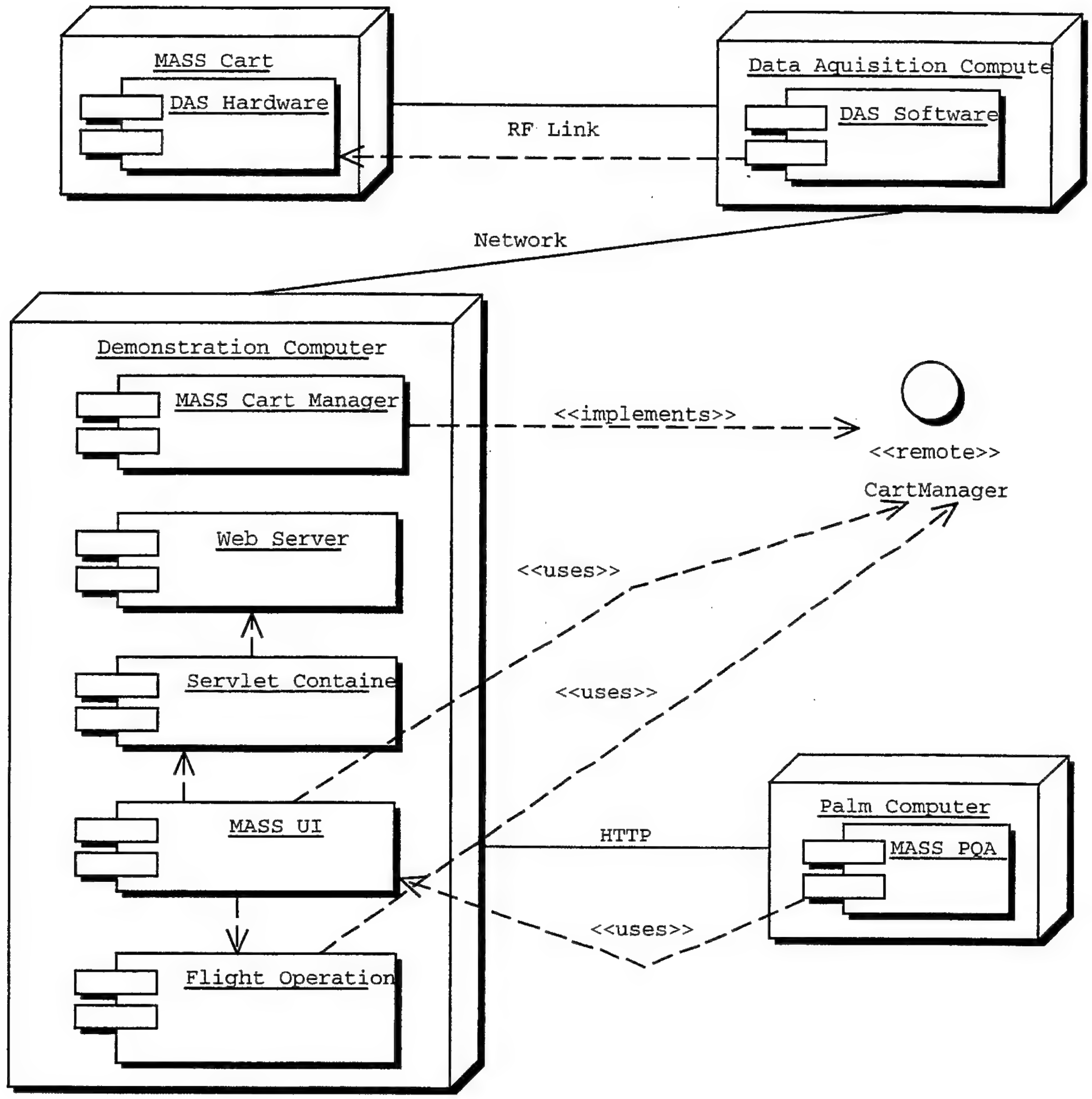


Figure 12-1: Software Architecture

12.1 Software Components

The system implemented consists of the following custom software components:

(1) Palm Query Application
(2) User Interface component
(3) Cart Manager component
(4) Flight Operations component

The following software components are also required:

(1) Web server
(2) Servlet Container

The PQA is like a mini-web site that is stored locally on the PalmV computer. All content in the PQA is static. Requests for dynamic content are handled by the MASS User Interface (UI) component. The MASS PQA contains a single HTML page with a list of links that act as gateways to the dynamic content provided by the system (see Figure 12-2).

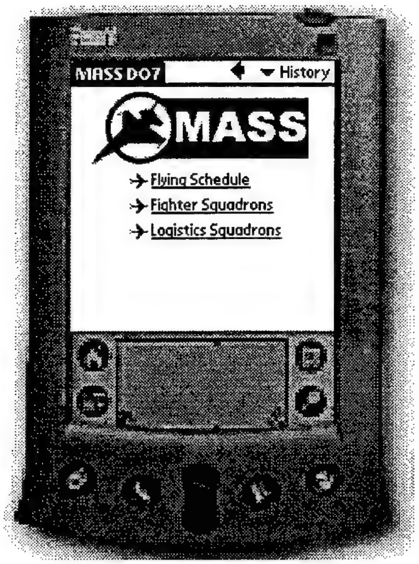


Figure 12-2: MASS PQA

The MASS UI component is responsible for the generation of all dynamic HTML pages. It is implemented as a set of Java Server Pages (JSPs). JSP is a Java technology for the development of dynamic web pages and requires a web server and servlet container to function properly. The PQA and MASS UI communicate via HTTP. The MASS UI relies heavily on the services of the Cart Manager and Flight Operations components in order to fulfill user requests for dynamic content.

The Cart Manager component manages a collection of EMS carts. The Cart Manager is responsible for monitoring each of the carts in its collection and making that data accessible to the MASS UI. The MASS UI communicates with the Cart Manager using RMI (Remote Method Invocation). RMI is a distributed object framework for the Java platform and provides a simple and direct model for distributed computation with Java objects.

The Flight Operations component is responsible for managing the daily operations schedule for a wing fighter squadron. It is implemented as a set of JavaBeans. JavaBeans is an architecture for both using and building components architecture. JSP has built-in support for JavaBeans, so no special mechanisms are needed for communication between the JSP pages in the MASS UI component and the JavaBeans in the Flight Operations component. The webserver we used was Apache from Apache Software Foundation and the servlet container was JRun from Allaire.

13. CONCLUSIONS (PART II)

The second part of DO7 demonstrated the ability to take data from the system defined in the first part and distribute it in an intelligent manner to the appropriate users. Data distributed in this way could be used to inform the users of the state of readiness of the AGE units but also to alert command personnel as to problems in allocation of resources. During Part II testing and demonstration data was tracked via remote wireless Palm Pilots and alerts were sent via email on present conditions based on a specific usage model.

A key lesson learned during the second part of DO7 was that a system to distribute data wirelessly, in an intelligent manner was feasible. This was accomplished by leveraging Java technology during system development and creating a prototype that was flexible, scalable, distributed, and platform independent.

Key accomplishments in part II of DO7 include:

- Implementation of a Java-based software platform for distribution of data from Part I over the worldwide web.
- Selection of a Palm Pilot with a wireless modem for demonstration of the proof of concept of the wireless data distribution
- Implementation of a software alert mechanism to send automated emails when AGE status reaches a critical threshold.

While all of the capabilities of this system were demonstrated individually and partially integrated, a complete demonstration was not accomplished due to the difficulties at AFRL's Wright-Patterson AFB facility with their system's firewall.

APPENDIX A: SAMPLE DATA

Sample Data taken over a one minute interval with a sampling time of five seconds. The ambient temperature and oil quality measurements are displayed below.

```
"TOA5","Logan","CR9000","1073","2.01","CPU:AFRL.DLD","13505
","SAMP5SEC"
"TIMESTAMP","RECORD","AmbTemp","OilQual"
"TS","RN","DEGREESF",""
"","","Smp","Smp"
"1999-11-16 11:21:20.352",44132,45.106032,5.547283
"1999-11-16 11:21:25.354",44133,45.35442,5.582094
"1999-11-16 11:21:30.356",44134,45.566742,5.271932
"1999-11-16 11:21:35.358",44135,45.657065,5.115754
"1999-11-16 11:21:40.36",44136,45.668355,5.143603
"1999-11-16 11:21:45.362",44137,45.614726,5.42993
"1999-11-16 11:21:50.364",44138,45.388605,5.45941
"1999-11-16 11:21:55.366",44139,45.774088,5.645695
"1999-11-16 11:22:00.368",44140,45.726048,5.431812
"1999-11-16 11:22:05.37",44141,45.361264,5.444043
"1999-11-16 11:22:10.372",44142,45.535637,5.0949931
"1999-11-16 11:22:15.374",44143,45.686176,5.0511498
```

APPENDIX B: DAS PROGRAM LISTING

```
'                           Program name: AFRL.DLD
'                             Written by: John Wood
'                            I.D. number: Number
'                           Date written: 11-05-1999
'                           Time written: 12:34:17
'                         PC9000 Version: 3.20

'This program was generated using Campbell Scientific's PC9000
'program generator for the Logger Measurement & Control System.

'            _____________ Logger CONFIGURATION _____________
'            Slot 1 = 9011    Slot 5 = 9060    Slot  9 = None
'            Slot 2 = 9031    Slot 6 = 9070    Slot 10 = None
'            Slot 3 = 9041    Slot 7 = 9055    Slot 11 = None
'            Slot 4 = 9050    Slot 8 = None    Slot 12 = None

'\\\\\\\\\\\\\\\\\\\\\\\ TIMING CONSTANTS ///////////////////////

Const PERIOD = 1                            'Scan interval number
Const P_UNITS = 2                           'Scan interval units (Secs)

Const INTERVAL1 = 1                         'Table 1 interval number
Const UNITS1 = 3                            'Table 1 interval units (Mins)

Const INTERVAL2 = 10                        'Table 2 interval number
Const UNITS2 = 3                            'Table 2 interval units (Mins)

Const INTERVAL3 = 6                         'Table 3 interval number
Const UNITS3 = 4                            'Table 3 interval units (Hrs)

'\\\\\\\\\\\\\\\\\\\\ THERMOCOUPLE CONSTANTS ////////////////////

'__________________________ Temp Block1 __________________________
Const TRNG1 = 17                            'Block1 measurement range (50 mV)
Const TTYPE1 = 2                            'Block1 thermocouple type (K)
Const TREP1 = 1                             'Block1 repetitions
Const TSETL1 = 30                           'Block1 settling time (usecs)
Const TINT1 = 40                            'Block1 integration time (usecs)
Const TMULT1 = 1.8                          'Block1 default multiplier
Const TOSET1 = 32                           'Block1 default offset
Dim TBlk1(TREP1)                            'Block1 dimensioned source
Units TBlk1 = Deg_F                         'Block1 default units (Deg_F)

'\\\\\\\\\\\\\\\\\\\\\ VOLTAGE CONSTANTS /////////////////////

'__________________________ Volt Block1 __________________________
Const VRNG1 = 0                             'Block1 measurement range (5000 mV)
Const VREP1 = 1                             'Block1 repetitions
Const VSETL1 = 30                           'Block1 settling time (usecs)
Const VINT1 = 40                            'Block1 integration time (usecs)
Const VMULT1 = 1                            'Block1 default multiplier
Const VOSET1 = 0                            'Block1 default offset
Dim VBlk1(VREP1)                            'Block1 dimensioned source
Units VBlk1 = mVolts                        'Block1 default units (mVolts)
'__________________________ Volt Block2 __________________________
Const VRNG2 = 0                             'Block2 measurement range (5000 mV)
Const VREP2 = 3                             'Block2 repetitions
Const VSETL2 = 30                           'Block2 settling time (usecs)
Const VINT2 = 40                            'Block2 integration time (usecs)
Const VMULT2 = 1                            'Block2 default multiplier
Const VOSET2 = 0                            'Block2 default offset
Dim VBlk2(VREP2)                            'Block2 dimensioned source
Units VBlk2 = mVolts                        'Block2 default units (mVolts)
'__________________________ Volt Block3 __________________________
Const VRNG3 = 0                             'Block3 measurement range (5000 mV)
Const VREP3 = 2                             'Block3 repetitions
Const VSETL3 = 30                           'Block3 settling time (usecs)
Const VINT3 = 40                            'Block3 integration time (usecs)
Const VMULT3 = 1                            'Block3 default multiplier
Const VOSET3 = 0                            'Block3 default offset
Dim VBlk3(VREP3)                            'Block3 dimensioned source
Units VBlk3 = mVolts                        'Block3 default units (mVolts)
'__________________________ Volt Block4 __________________________
Const VRNG4 = 0                             'Block4 measurement range (5000 mV)
Const VREP4 = 1                             'Block4 repetitions
```

```
Const VSETL4 = 30                          'Block4 settling time (usecs)
Const VINT4 = 40                           'Block4 integration time (usecs)
Const VMULT4 = 1                           'Block4 default multiplier
Const VOSET4 = 0                           'Block4 default offset
Dim VBlk4(VREP4)                           'Block4 dimensioned source
Units VBlk4 = mVolts                       'Block4 default units (mVolts)
'_____________________ Volt Block5 _____________________
Const VRNG5 = 17                           'Block5 measurement range (50 mV)
Const VREP5 = 1                            'Block5 repetitions
Const VSETL5 = 30                          'Block5 settling time (usecs)
Const VINT5 = 40                           'Block5 integration time (usecs)
Const VMULT5 = 1                           'Block5 default multiplier
Const VOSET5 = 0                           'Block5 default offset
Dim VBlk5(VREP5)                           'Block5 dimensioned source
Units VBlk5 = mVolts                       'Block5 default units (mVolts)
'_____________________ Volt Block6 _____________________
Const VRNG6 = 0                            'Block6 measurement range (5000 mV)
Const VREP6 = 1                            'Block6 repetitions
Const VSETL6 = 30                          'Block6 settling time (usecs)
Const VINT6 = 40                           'Block6 integration time (usecs)
Const VMULT6 = 1                           'Block6 default multiplier
Const VOSET6 = 0                           'Block6 default offset
Dim VBlk6(VREP6)                           'Block6 dimensioned source
Units VBlk6 = mVolts                       'Block6 default units (mVolts)

'\\\\\\\\\\\\\\\\\\\\ HIGH VOLTAGE CONSTANTS ////////////////////

'___________________ High Volt Block1 ___________________
Const HRNG1 = 6                            'Block1 measurement range (50 Volts)
Const HREP1 = 1                            'Block1 repetitions
Const HSETL1 = 30                          'Block1 settling time (usecs)
Const HINT1 = 40                           'Block1 integration time (usecs)
Const HMULT1 = 1                           'Block1 default multiplier
Const HOSET1 = 0                           'Block1 default offset
Dim HBlk1(HREP1)                           'Block1 dimensioned source
Units HBlk1 = Volts                        'Block1 default units (Volts)
'___________________ High Volt Block2 ___________________
Const HRNG2 = 6                            'Block2 measurement range (50 Volts)
Const HREP2 = 3                            'Block2 repetitions
Const HSETL2 = 30                          'Block2 settling time (usecs)
Const HINT2 = 40                           'Block2 integration time (usecs)
Const HMULT2 = 1                           'Block2 default multiplier
Const HOSET2 = 0                           'Block2 default offset
Dim HBlk2(HREP2)                           'Block2 dimensioned source
Units HBlk2 = Volts                        'Block2 default units (Volts)
'___________________ High Volt Block3 ___________________
Const HRNG3 = 6                            'Block3 measurement range (50 Volts)
Const HREP3 = 5                            'Block3 repetitions
Const HSETL3 = 30                          'Block3 settling time (usecs)
Const HINT3 = 40                           'Block3 integration time (usecs)
Const HMULT3 = 1                           'Block3 default multiplier
Const HOSET3 = 0                           'Block3 default offset
Dim HBlk3(HREP3)                           'Block3 dimensioned source
Units HBlk3 = Volts                        'Block3 default units (Volts)

'\\\\\\\\\\\\\\\\\\ ALIASES & OTHER VARIABLES //////////////////

Alias TBlk1(1) = Amb_Temp                  'Assign alias name Amb_Temp to TBlk1(1)
Alias VBlk1(1) = OilQuality                'Assign alias name OilQuality to VBlk1(1)
Alias VBlk2(1) = VPhase1                   'Assign alias name VPhase1 to VBlk2(1)
Alias VBlk2(2) = VPhase2                   'Assign alias name VPhase2 to VBlk2(2)
Alias VBlk2(3) = VPhase3                   'Assign alias name VPhase3 to VBlk2(3)
Alias VBlk3(1) = InletPres                 'Assign alias name InletPres to VBlk3(1)
Alias VBlk3(2) = OutletPres                'Assign alias name OutletPres to VBlk3(2)
Alias VBlk4(1) = ExhaustPres               'Assign alias name ExhaustPres to VBlk4(1)
Alias VBlk5(1) = Barometric                'Assign alias name Barometric to VBlk5(1)
Alias VBlk6(1) = CrankPos                  'Assign alias name CrankPos to VBlk6(1)
Alias HBlk1(1) = CoolanLvl                 'Assign alias name CoolanLvl to HBlk1(1)
Alias HBlk2(1) = FuelQty                   'Assign alias name FuelQty to HBlk2(1)
Alias HBlk2(2) = CoolTemp                  'Assign alias name CoolTemp to HBlk2(2)
Alias HBlk2(3) = BattVolt                  'Assign alias name BattVolt to HBlk2(3)
Alias HBlk3(1) = CPhase1                   'Assign alias name CPhase1 to HBlk3(1)
Alias HBlk3(2) = CPhase2                   'Assign alias name CPhase2 to HBlk3(2)
Alias HBlk3(3) = CPhase3                   'Assign alias name CPhase3 to HBlk3(3)
Alias HBlk3(4) = Frequency                 'Assign alias name Frequency to HBlk3(4)
Alias HBlk3(5) = PercentPwr                'Assign alias name PercentPwr to HBlk3(5)
Public Flag(8)                             'General Purpose Flags
Public BattVolt                            'Battery voltage
Units BattVolt = Volts                     'Battery voltage units
Public BattCurr                            'Battery current
Units BattCurr = mAmps                     'Battery current units
```

```
Dim TRef(1)                                    'Declare Reference Temp variable

'\\\\\\\\\\\\\\\\\\\\\\\ OUTPUT SECTION ////////////////////////

'---------------------------- Table 1----------------------------
DataTable(SAMP1MIN,True,10000)                 'Trigger, 10000 records
   DataInterval(0,INTERVAL1,UNITS1,1000) '1 Min interval, 1000 lapses, 6.94 Days
   '_____________________ Thermocouple Blocks ____________________
   Sample (TREP1,TBlk1(),FP2)                  '1 Reps,Source,Res
   '_______________________ Voltage Blocks ______________________
   Sample (VREP1,VBlk1(),FP2)                  '1 Reps,Source,Res
   Sample (VREP3,VBlk3(),FP2)                  '2 Reps,Source,Res
   Sample (VREP4,VBlk4(),FP2)                  '1 Reps,Source,Res
   Sample (VREP5,VBlk5(),FP2)                  '1 Reps,Source,Res
   '_____________________ High Voltage Blocks ____________________
   Sample (HREP2,HBlk2(),FP2)                  '3 Reps,Source,Res
EndTable                                       'End of table SAMP1MIN

'---------------------------- Table 2----------------------------
DataTable(SAMP10MI,True,10000)                 'Trigger, 10000 records
   DataInterval(0,INTERVAL2,UNITS2,1000) '10 Min interval, 1000 lapses, 69.44 Days
   '_______________________ Voltage Blocks ______________________
   Sample (VREP2,VBlk2(),FP2)                  '3 Reps,Source,Res
   Sample (VREP4,VBlk4(),FP2)                  '1 Reps,Source,Res
   Sample (VREP5,VBlk5(),FP2)                  '1 Reps,Source,Res
   Sample (VREP6,VBlk6(),FP2)                  '1 Reps,Source,Res
   '_____________________ High Voltage Blocks ____________________
   Sample (HREP2,HBlk2(),FP2)                  '3 Reps,Source,Res
   Sample (HREP3,HBlk3(),FP2)                  '5 Reps,Source,Res
EndTable                                       'End of table SAMP10MI

'---------------------------- Table 3----------------------------
DataTable(SAMP6HR,True,2000)                   'Trigger, 2000 records
   DataInterval(0,INTERVAL3,UNITS3,200)  '6 Hour interval, 200 lapses, 500.00 Days
   '_______________________ Voltage Blocks ______________________
   Sample (VREP1,VBlk1(),FP2)                  '1 Reps,Source,Res
   '_____________________ High Voltage Blocks ____________________
   Sample (HREP1,HBlk1(),FP2)                  '1 Reps,Source,Res
EndTable                                       'End of table SAMP6HR

'\\\\\\\\\\\\\\\\\\\\\\\\\\\ PROGRAM ///////////////////////////

BeginProg                                      'Program begins here
   Scan(PERIOD,P_UNITS,0,0)                    'Scan once every 1Secs, non-burst
      Battery(BattVolt,0)                      'Battery voltage measurement
      Battery(BattCurr,1)                      'Battery current measurement
      '__________________________ Temp Blocks _______________________
      ModuleTemp(TRef(),1,4,20)                'RefTemp,CardCount,StartCard,Integrate
      TCDiff(TBlk1(),TREP1,TRNG1,4,1,TTYPE1,TRef(1),True,TSETL1,TINT1,TMULT1,TOSET1)
      '__________________________ Volt Blocks _______________________
      VoltSE(VBlk1(),VREP1,VRNG1,4,3,VSETL1,VINT1,VMULT1,VOSET1)
      VoltSE(VBlk2(),VREP2,VRNG2,4,4,VSETL2,VINT2,VMULT2,VOSET2)
      VoltSE(VBlk3(),VREP3,VRNG3,4,7,VSETL3,VINT3,VMULT3,VOSET3)
      VoltSE(VBlk4(),VREP4,VRNG4,4,9,VSETL4,VINT4,VMULT4,VOSET4)
      VoltSE(VBlk5(),VREP5,VRNG5,4,10,VSETL5,VINT5,VMULT5,VOSET5)
      VoltSE(VBlk6(),VREP6,VRNG6,4,11,VSETL6,VINT6,VMULT6,VOSET6)
      '______________________ High Volt Blocks ______________________
      VoltSE(HBlk1(),HREP1,HRNG1,7,1,HSETL1,HINT1,HMULT1,HOSET1)
      VoltDiff(HBlk2(),HREP2,HRNG2,7,2,False,HSETL2,HINT2,HMULT2,HOSET2)
      VoltDiff(HBlk3(),HREP3,HRNG3,7,5,True,HSETL3,HINT3,HMULT3,HOSET3)
      CallTable SAMP1MIN                       'Go up and run Table SAMP1MIN
      CallTable SAMP10MI                       'Go up and run Table SAMP10MI
      CallTable SAMP6HR                        'Go up and run Table SAMP6HR
   Next Scan                                   'Loop up for the next scan

'\\\\\\\\\\\\\\\\\\\\\\\ LOW PRIORITY ////////////////////////

   SlowSequence                                'Used for slow measurements
   Dim TripVolt                                'Dimension TripVolt
   Scan(60,Sec,0,0)                            'Scan once every 60 seconds
      Calibrate                                'Corrects ADC offset and gain
      BiasComp                                 'Corrects ADC bias current
      '______________________ Battery Saver ______________________
      Battery(TripVolt,0)                      'Battery voltage measurement
      AvgRun(TripVolt,1,TripVolt,10)           'Running average (10 mins) of TripVolt
      If TripVolt < 11.5 Then                  'Test for less than 11.5 volts
         PowerOff(0,0,Min)                     'Kill the Logger
      End If
      '--------------------------------------------------------------
   Next Scan                                   'Loop up for the next scan
EndProg                                        'Program ends here
```

```
'***** Program End *****
```

APPENDIX C: TEST PROCEDURE

The test specification described the method that was used to verify data acquisition, sensor, and RF link operation. There were two broad classifications of tests. Bench tests were used to verify proper operation of the components under conditions that could not be simulated using the MEP-804A. System tests were used to verify proper operation of the components in the actual operating environment.

C-1 Data Acquisition System Bench Test

The Campbell Scientific data logger and associated input/output modules were tested to verify the following:

- Proper operation of each module
- Download capability
- Communications link w/o RF module

To perform the tests, the following items were required:

- Campbell Scientific Data Logger
- Campbell Scientific Modules
- TL925 RS485 to RS232 Converter
- PC w/ CR9000 Software installed
- Oscilloscope
- Signal Generator

The CR9000 software was used to generate test for the various input/output modules. Figure C-1 shows the basic configuration for the CR9000 bench test configuration.

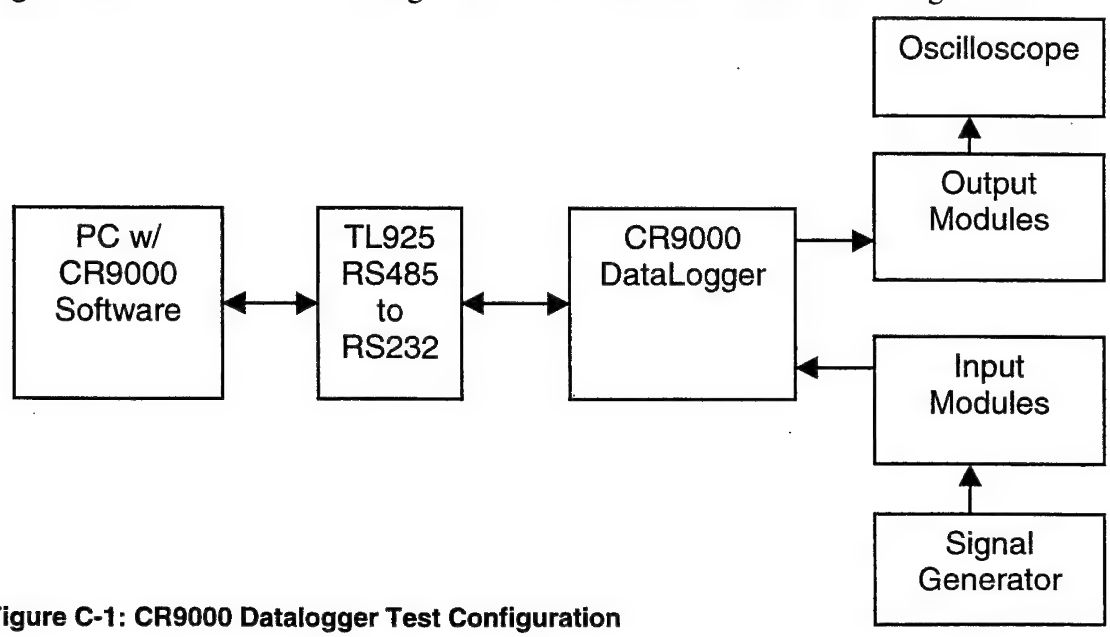


Figure C-1: CR9000 Datalogger Test Configuration

CR9000 modules were input, output, or both. The features of each module were tested prior to system installation. Applying a known signal at an input pin and verifying that this signal was measured by the CR9000 was used to test the input modules.

The CR9000 software was configured to control the output modules. The oscilloscope was used to measure the output. The output was expected to be within the tolerance given by Campbell Scientific.

C-2 RF Link Bench Test

The RF Link was tested to ensure that both the range and data rate requirements were satisfactory. The ADAM-4550 is packaged with software that was used to perform range testing. The following items were required for testing the RF Link:

- Two ADAM-4550 Radio Modems
- Two IBM Compatible PC's with one serial port
- Two Standard RS-232 cables
- Campbell Scientific Data Logger with 5V analog input module
- TL925 RS485 to RS232 Converter
- Digital Multi-meter
- Adjustable Power Supply

The initial test for the RF Link hardware was performed using two PCs. The diagram in Figure C-2 shows how the hardware was assembled to conduct this test.

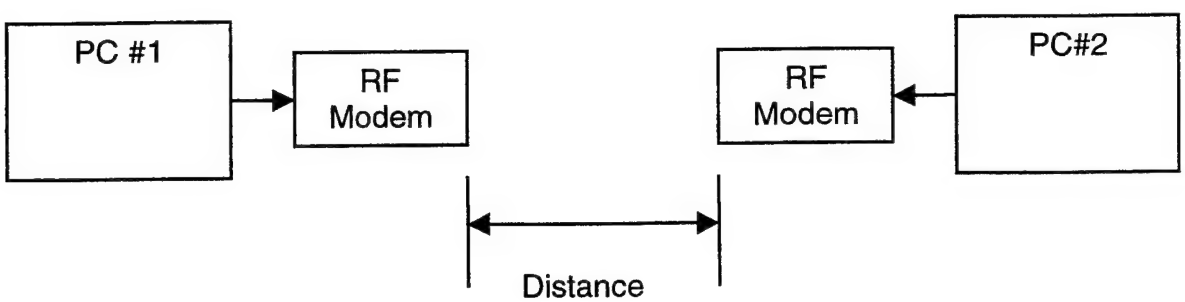


Figure C-2: RF Test Configuration 1

The supplied software was used to verify that the RF Link is operational over varied distances.

After testing the basic RF modems had been accomplished, interface to the Campbell Scientific data logger was tested. Testing was similar to above except the second PC was replaced by the data logger and interface hardware as shown in Figure C-3.

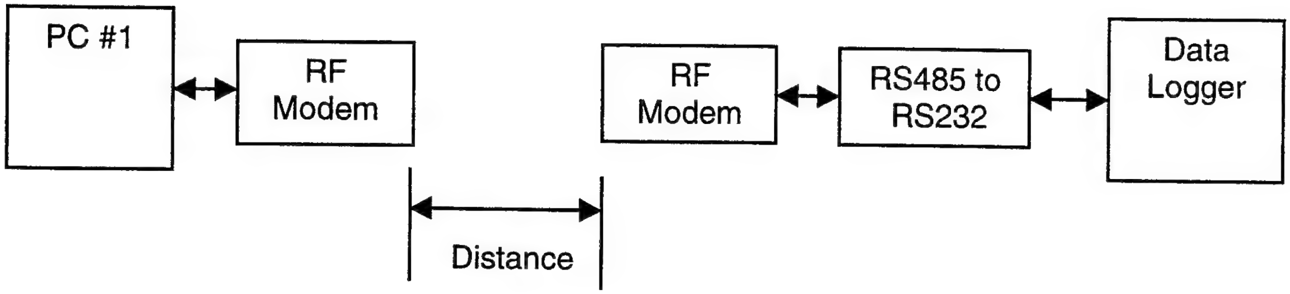


Figure C-3: RF Test Configuration 2

The data logger 5V analog board was installed for this test. A test signal was applied to analog input 0. A test program that monitored the signal on this pin was downloaded over the RF Link. Proper operation of the RF Link was tested by varying the signal on the analog input pin and verifying that the reported data was received and matched that of the input. This was performed at varying distances to verify the range determined in the previous step.

C-3 Sensor Bench Tests

Each new sensor was bench tested prior to installation. The bench tests were required to verify operation under conditions that would only be indicated by failure of the MEP-804A. Actual failure on the system was not possible without damage to the generator set. Sensors that currently exist on the MEP-804A were not bench tested. The following sections describe the tests that were used to verify operation and perform some initial characterization the new sensors.

C-3.1 Oil Quality

The Oil Quality sensor was tested under a range of conditions. The test procedure was as follows:

1. Connect a regulated 5V supply to the Sensor, Red = +5, Black = GND.
2. Connect a digital multi-meter between the signal (Green Wire) and Ground.
3. Apply power to the sensor.
4. Place the sensor into a sample of new oil.
5. Measure the output.
6. Clean the sensor.
7. Place the sensor in a sample of old oil.
8. Measure the output.
9. Clean the sensor.
10. Place the sensor into the sample of new oil.
11. Place a measured amount of coolant into the new sample.
12. Measure the output.
13. Repeat the last two steps several times with the same amount.
14. Plot the results of the test as output vs. contaminant.

C-3.2 Oil Pressure/Differential Pressure

The oil pressure/differential pressure employed two Kavlico pressure transducers. Testing was performed by connecting the sensor to a calibrated pressure source and measuring the output of the sensor on a digital multi-meter. Testing was performed using the following procedure:

1. Connect a regulated 5V supply to the Sensor, Red = +5, Black = GND.
2. Connect a digital multi-meter between the signal (Green Wire) and Ground.
3. Apply power to the sensor.
4. Connect the pressure end of the sensor to a calibrated pressure source.
5. Apply pressure ranging from 0 psi to 100 psi in 5 psi increments.
6. Measure the output and log the pressure for each setting.
7. Plot the results.

C-3.3 Coolant Sensors

The coolant sensor test was performed by installing the sensor in the coolant bottle and filling the bottle incrementally and measuring the output with a digital multi-meter. Testing was performed using the following procedure.

1. Connect a regulated 12V supply to the Sensor, Red = +5, Black = GND
2. Connect a digital multi-meter between the signal (Green Wire) and Ground
3. Ensure the coolant filler bottle is empty
4. Install the sensor into the coolant filler bottle
5. Apply power to the sensor
6. Measure the empty level
7. Raise the coolant level in ½ inch increments and measure the output
8. Plot the data

C-3.4 Engine Misfire Detection

The engine misfire parameter employed two new sensors and one existing sensor. The new sensors are a Kavlico pressure transducer and an Omron optical sensor.

The Kavlico pressure transducer was connected to a known pressure source and its output measured on a digital multi-meter. The power connections were monitored with a digital multi-meter.

Testing was performed using the following procedure:

1. Connect a regulated 5V supply to the Sensor, Red = +5, Black = GND.
2. Connect a digital multi-meter between the signal (Green Wire) and Ground.
3. Apply power to the sensor.
4. Connect the pressure end of the sensor to a calibrated pressure source.
5. Apply pressure ranging from 0 psi to 5 psi in 1 psi increments.
6. Measure the output and log the pressure for each setting.
7. Plot the results.

The Omron optical sensor was tested by mounting the sensor in proximity to a rotating disk. The speed of the disk was measured. A white marking was placed on the disk. The output of the sensor was measured using an oscilloscope.

Testing was performed using the following procedure:

1. Connect a regulated 12V supply to the Sensor, Red = +5, Black = GND.
2. Connect a digital multi-meter between the signal (Green Wire) and Ground.
3. Apply power to the sensor.
4. Paint a white mark onto a rotating disk.
5. Rotate the disk at a known speed.
6. Verify that the speed indicated by the sensor matches that of the disk.

C-3.5 Barometric Pressure

The barometric pressure sensor was tested using an independent calibrated barometer as a reference. The values were compared in two different pressure environments.

1. Connect a +12V supply to the power inputs on the sensor.
2. Connect a digital multimeter between the output signals of the sensor (V out, GND).
3. Apply power to the sensor.
4. Calculate barometric pressure from the voltage output P (in hPa) = (Data x 52) + 800.
5. Check value with respect to the calibrated barometer.
6. Repeat in a different pressure environment.

C-4 System Test at AFRL

This test provided both hardware and software testing. System testing assumed that all components were installed on the MEP-804A. The system test was first performed on a sensor by sensor basis to ensure proper installation of the system. Initial testing was performed at an accelerated sampling time to quickly isolate problems. Upon successful completion, the system was run at normal sampling rates. The accelerated test was a time scaled test performed with a 1 day = 1 hour scaling factor. The system test was performed as follows:

1. Place host PC in proximity to the MEP-804.
2. Turn on data acquisition system power.
3. Start diesel generator.
4. Connect generator set to a test load bank and adjust for a 50% load.
5. Verify that the Fuel Quantity matches the Fuel quantity gauge on the MEP-804 genset.
6. Visually verify the coolant level. It should coincide with the coolant level measured by the DAS within limits of experimental error.
7. Monitor the percent power gauge. Verify that it is at 50% load.
8. Monitor the voltage for phase 1.
9. Verify that the voltages are the same within limits of experimental error.
10. Repeat steps 13, 14, and 15 for phases 2 and 3.
11. Monitor the current for phase 1.
12. Repeat steps 17, 18, and 19 for phases 2 and 3.

13. Monitor the frequency.
14. Monitor the oil quality. With new oil in the diesel genset the reading should be approximately the same as that of the bench test for the same oil.
15. Remove the exhaust pressure sensor. Mount a ¼ T and install the sensor to one end of the T and a pressure gauge to the other.
16. Start the engine.
17. Monitor the pressure gauge and the sensor reading.
18. Monitor the engine speed sensor.

APPENDIX D: TEST PROCEDURE

D-1 Oil Quality Sensor

The oil quality sensor, which has an M20X1.5 male thread, was installed on the side of the engine oil pan so that it is below the minimum oil level. The sensor was screwed into a threaded mounting boss that is to be welded to the pan. The following procedure was used to install the sensor:

1. Drain the oil.
2. Remove the oil pan from the engine.
3. Lay out and drill a 1-inch diameter hole in the side of the oil pan in accordance with Figure D-1.
4. Center the mounting boss shown in Figure D-2 over the hole, and weld it all around to the oil pan.
5. Re-install the oil pan on the engine.
6. Install the oil quality sensor in the mounting boss, first lubricating the O-ring on the sensor with engine oil.
7. Fill the engine with the specified oil and check for leaks.

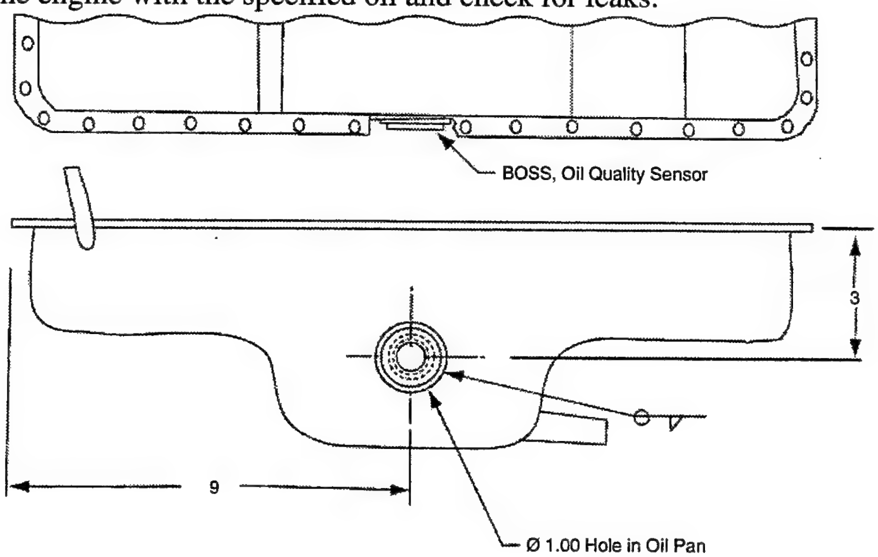


Figure D-1: Oil Quality Mounting Diagram

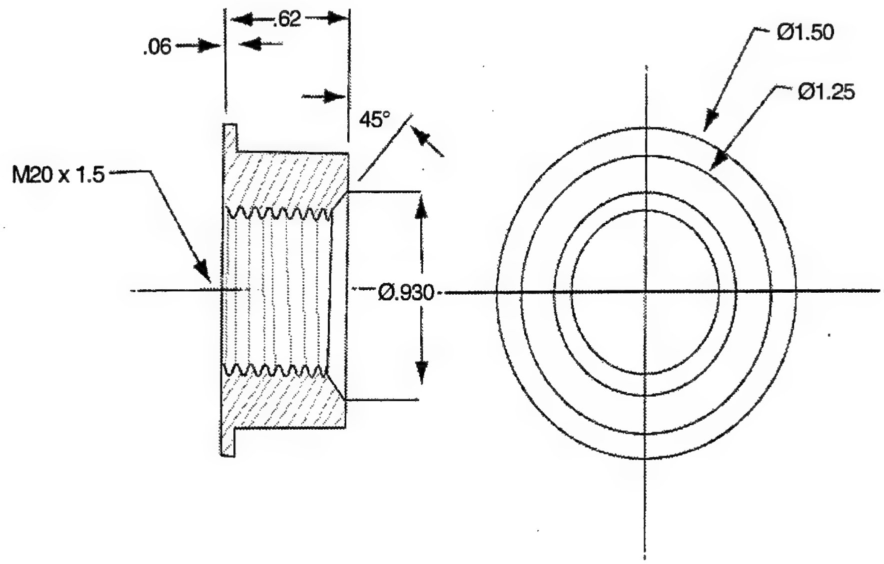


Figure D-2: Oil Quality Sensor Braze-on

D-2 Oil Pressure/Differential Pressure

Two oil pressure sensors were installed, to monitor engine oil pressure and pressure drop across the oil filter. One sensor was installed using a tee in an existing pressure tap. To install the other, a hole was drilled and tapped in the casting that mounts the oil filter. The following procedure was used to install the sensor:

1. Remove the oil filter from the engine.
2. Remove the oil filter casting from the engine. Take care not to damage the sealing O-ring on the flange of the casting. Remove this O-ring and set it aside.
3. Lay out, drill, and tap a ¼ NPT hole in the casting in accordance with Figure D-3.
4. Thoroughly clean the casting and replace the O-ring in its groove.
5. Re-install the casting on the engine.
6. Install an oil pressure sensor in the tapped hole in the casting, using a suitable pipe thread sealing compound or a limited amount of teflon tape. The threads must make a ground contact with the casting.
7. Remove the existing oil pressure sensor and its adapter from the engine.
8. Using thread sealant as above, install a street tee, 1/8 NPT, in place of the sensor.
9. Re-install the existing sensor on one leg of the tee, using sealant as above.
10. On the other leg of the tee, install a ¼ x 1/8 reducing adapter and the second oil pressure sensor, using thread sealant as above.

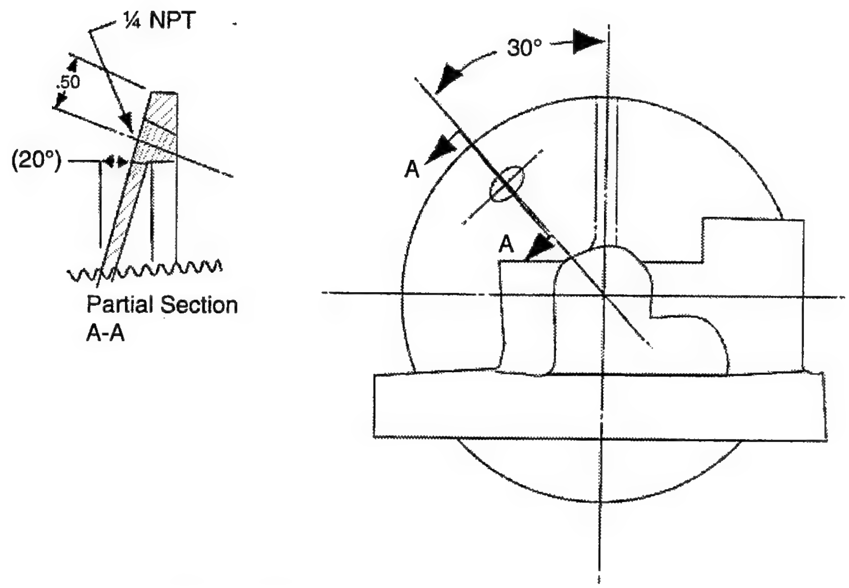


Figure D-3: Oil Inlet Pressure Mounting Diagram

D-3 Coolant Level

The coolant level sensor is a float-type device that was installed in the cap of the coolant overflow bottle. The sensor was modified slightly to enable mounting to the cap, and holes are to be cut in the cap. The following procedure was used to install the sensor:

1. Remove the cap from the coolant overflow bottle.
2. Machine a ¾-inch diameter hole in the center of the cap, and three 1/8-inch diameter holes on a 1-3/8-inch diameter bolt circle.
3. Measure the location of the "Gripring" at the end of the stem of the sensor, and remove the "Gripring" and the float.
4. Machine the bolt pattern in step 2 in the flange of the sensor.
5. Thread the stem of the sensor through the hole in the cap, and attach the flange using #4-40 stainless steel hardware.
6. Re-install the float and the "Gripring" on the stem of the sensor, referring to the measurement made in step 3.
7. Re-install the cap on the overflow bottle.

D-4 Engine Misfire Detection

There were two sensors necessary for detection of engine misfire: a pressure sensor in the exhaust manifold, and a photo-optical sensor to determine crankshaft position. The pressure sensor was installed in a half-coupling that is to be welded to the exhaust connector. The photo-optical sensor was mounted on a specially made bracket so that it picked up a reflective spot that was placed on the crankshaft pulley. The following procedure was used to install the sensor:

1. Disconnect the exhaust pipe from the exhaust connector.
2. Remove the exhaust connector from the exhaust manifold.

3. At a suitable location on the exhaust connector, drill a 3/8-inch diameter hole through one wall.
4. Position a stainless steel half-coupling, ¼ NPT, over the hole, and weld all around.
5. Re-install the exhaust connector on the exhaust manifold.
6. Re-connect the exhaust pipe.
7. Install the pressure sensor in the half-coupling. Do not use thread sealant.
8. Fabricate the bracket shown in Figure D-4.
9. Remove the two bolts near the timing indicator that retain the injector pump drive housing at the front of the engine block.
10. Install the bracket on the engine, using the two bolts just removed.
11. Mount the photo-optical sensor on the bracket.
12. Rotate the engine to the top dead center position, aligning the timing mark on the crankshaft pulley with the timing indicator. The number one piston must be in the compression part of its cycle.
13. Place a stripe of white paint 1/8 inch wide on the back face of the crankshaft pulley, opposite the sensor.

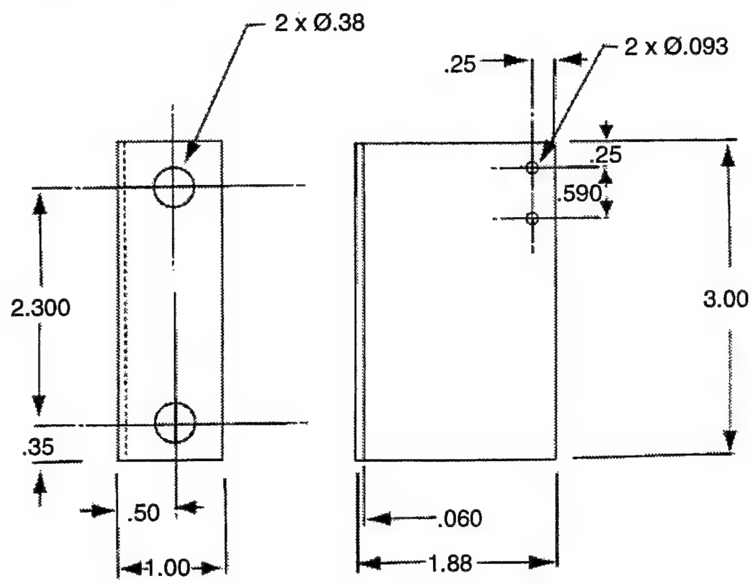


Figure D-4: Optical Sensor Mounting Bracket

D-5 Data Acquisition System (DAS)

The DAS was mounted within the housing of the generator set, behind the access door on the manifold side of the engine. It was supported by two angle brackets that vertically span the access opening and are bolted to the inside of the housing. The following procedure was used to install the sensor:

1. Open the access door on the manifold side of the engine, and remove the document box from the inside of the door.
2. Lay out and drill four holes .28 inch diameter in the generator set housing, per Figure D-5.

3. Temporarily install two angle brackets (Figure D-6 as shown in Figure D-5 using four spacers (Figure 3-D) and ¼-20 hardware. Use flat washers over the slots in the brackets.
4. Position the data acquisition system between the brackets, leaving a gap of 2 or 3 inches at the top. Mark the position on the two brackets.
5. Remove the data acquisition system and the brackets from the unit.
6. Fasten the brackets to the data acquisition system, in the position previously marked, using appropriate hardware.
7. Install the assembly into the generator set housing.

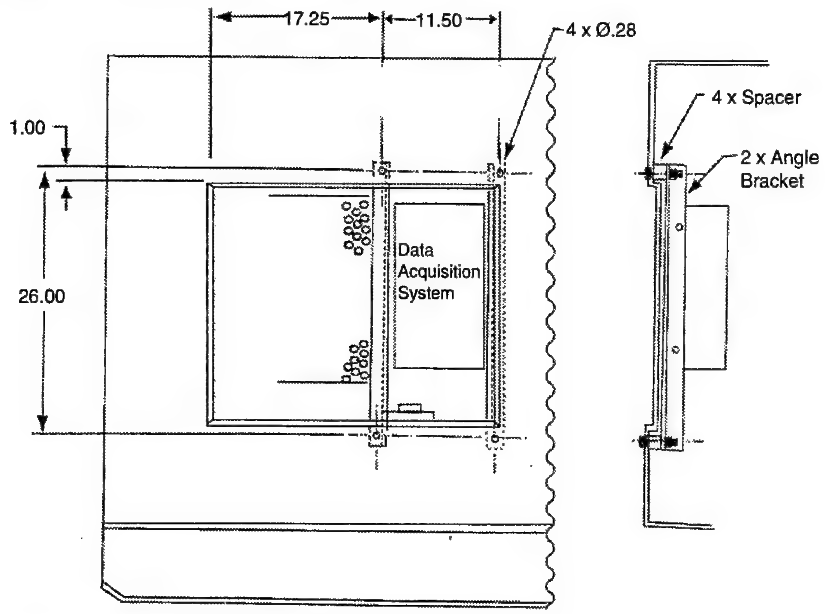


Figure D-5: DAS Mounting Diagram

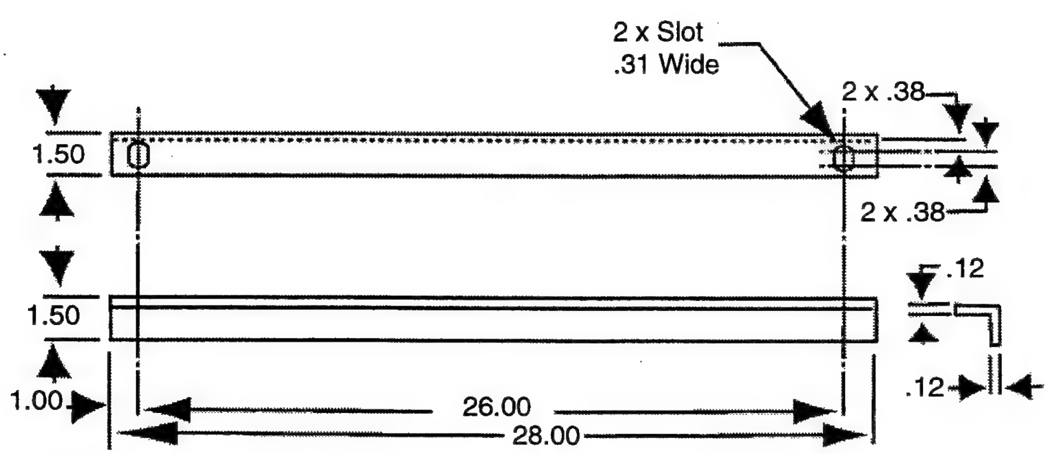


Figure D-6: DAS Mounting Brace

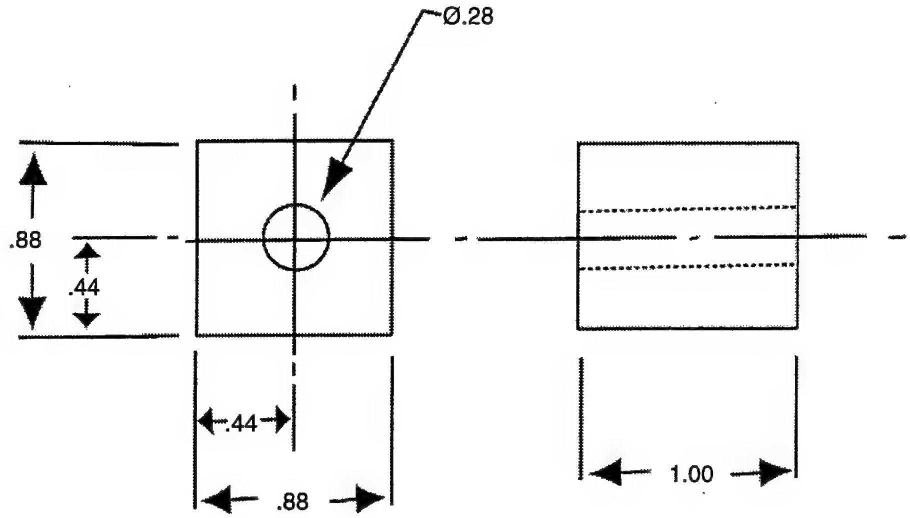


Figure D-7: DAS Mounting Spacer

APPENDIX E: SCHEMATIC DIAGRAMS

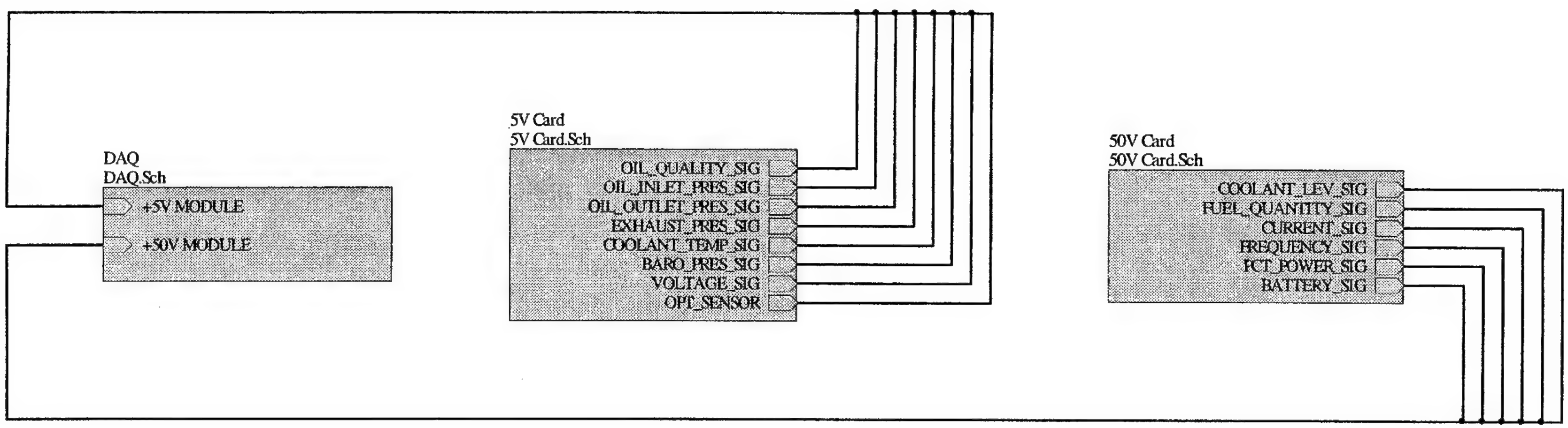


Figure E-1: High-Level System Schematic

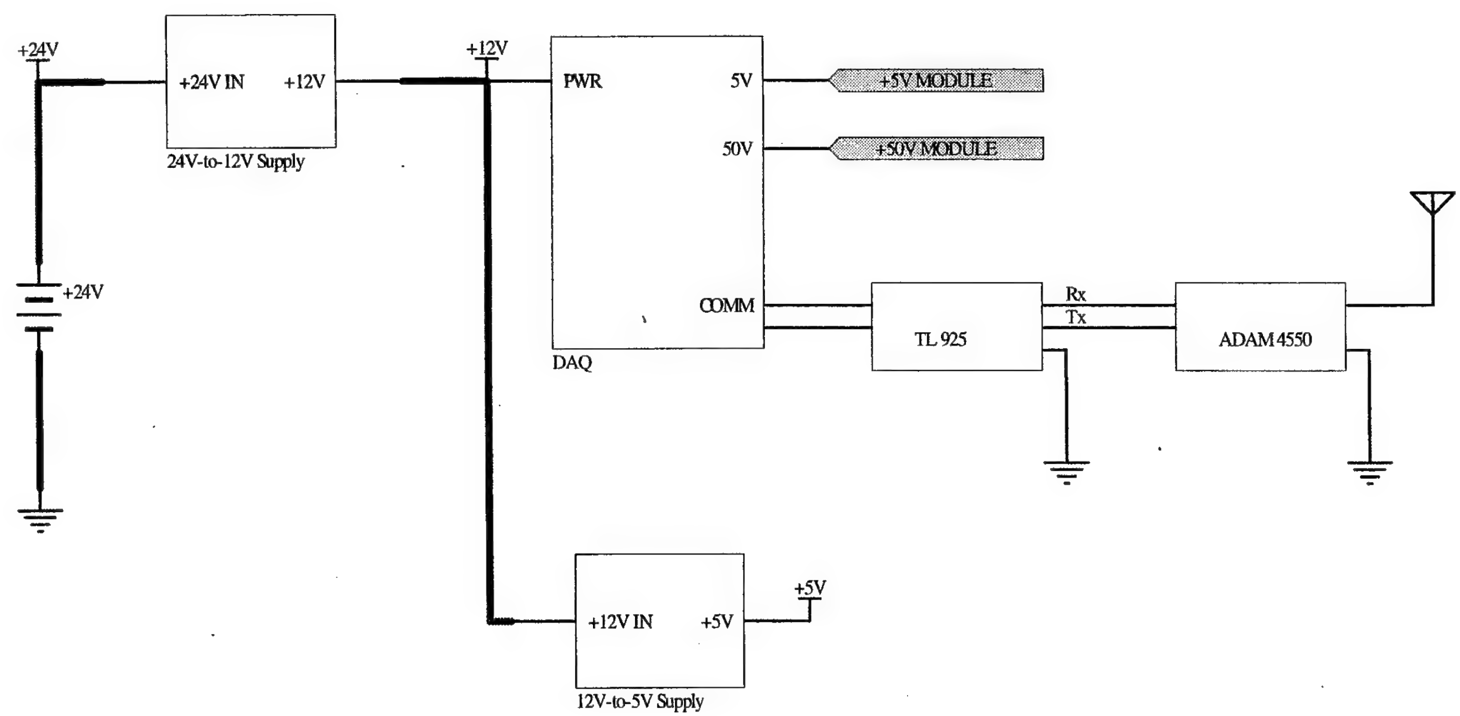


Figure E-2: DAS Interconnect Diagram

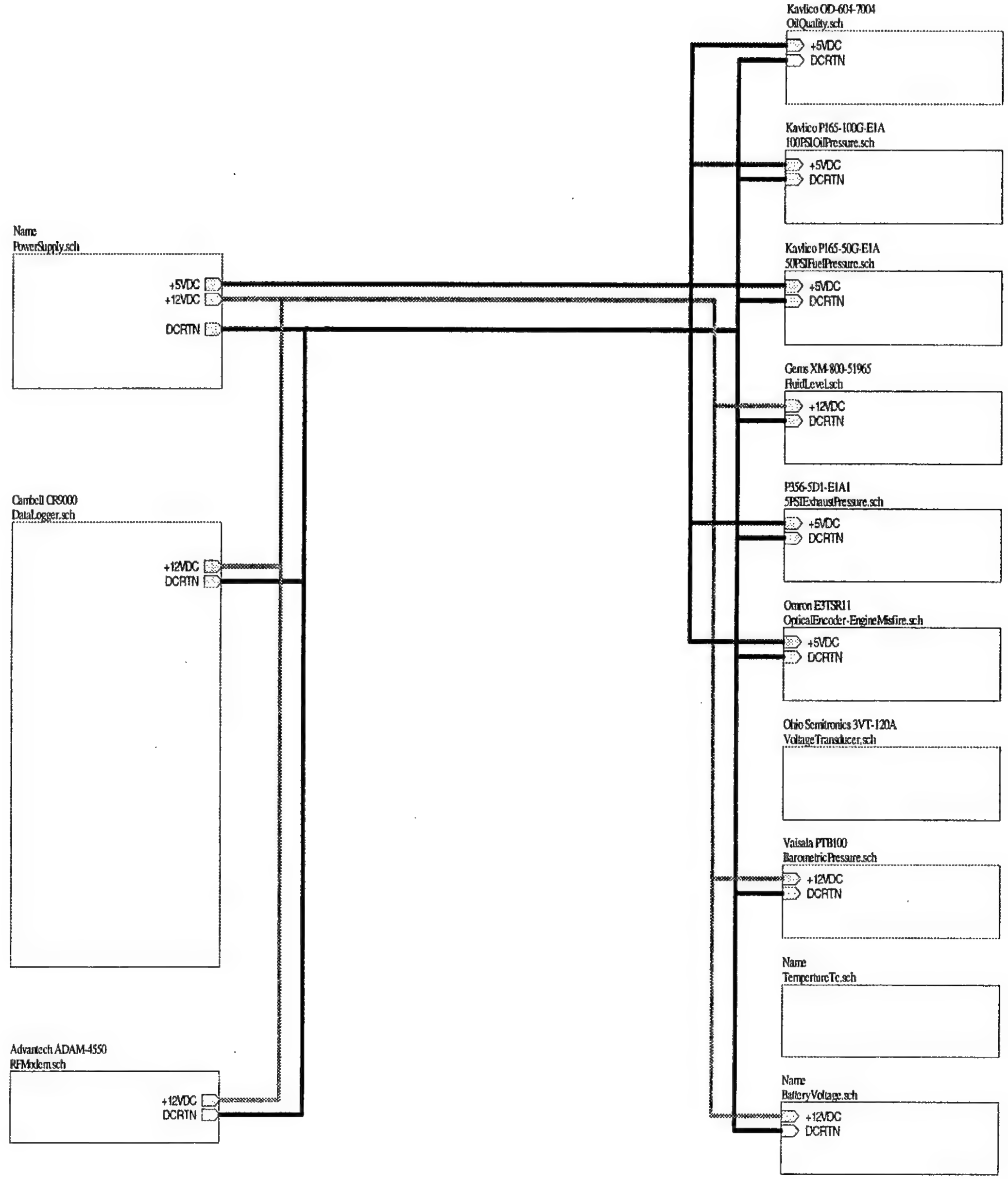


Figure E-3: DC Power Distribution

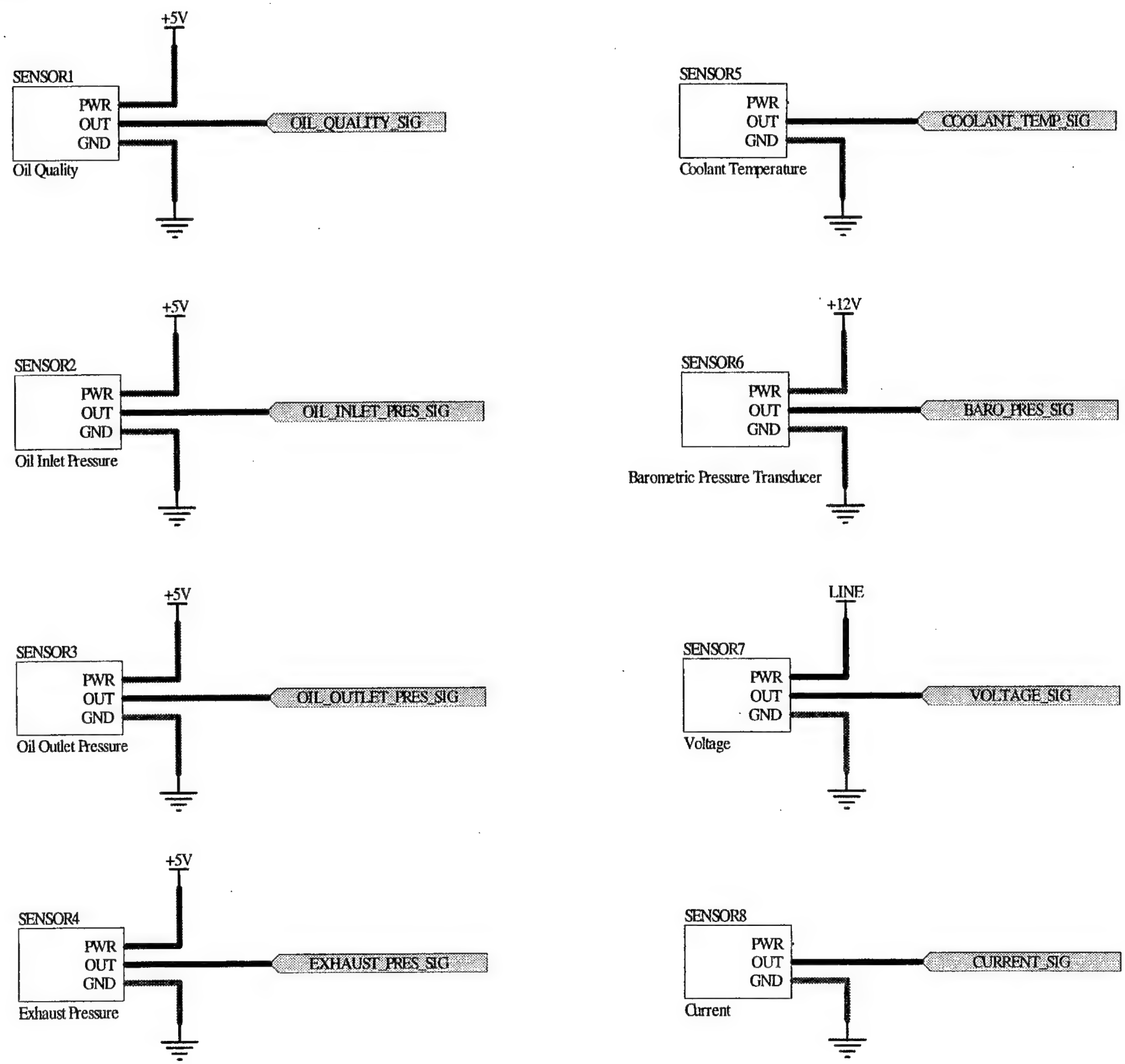


Figure E-4: 5V Module Signal Distribution

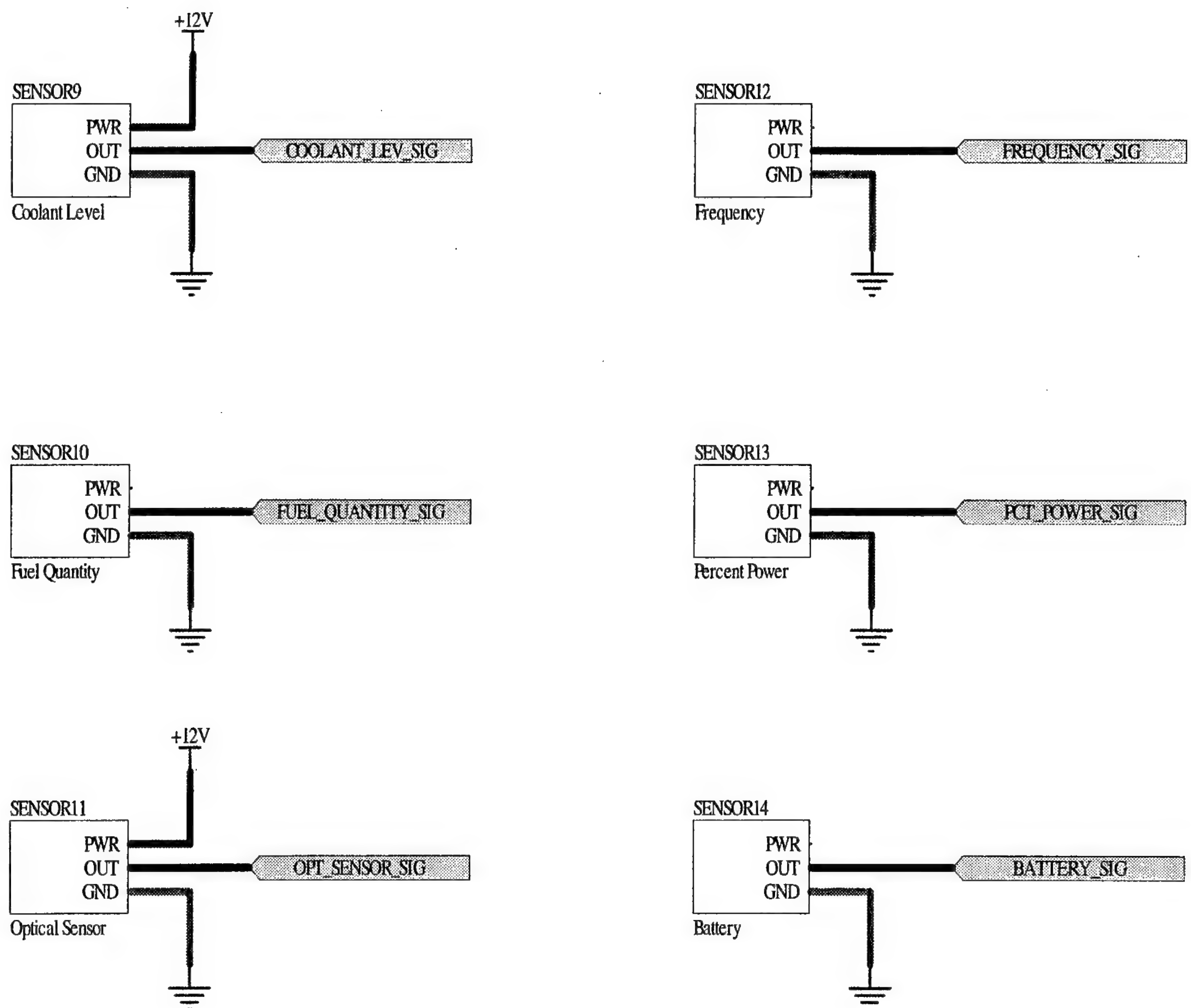


Figure E-5: 50V Module Signal Distribution

Concept of Operations (CONOPS)
For

Modular Aircraft Support System (MASS)
Delivery Order #7

Version 3

Prepared for:

US Air Force Research Laboratory (AFRL)

Human Effectiveness Directorate

Deployment and Sustainment Division

Logistics Readiness Branch (AFRL/HESR)

Attn: Captain Rudy W. Cardona

2698 G. Street, Bldg. 190

WRIGHT-PATTERSON, AFB, OH 45433-7604

14.15 MAY 00

15. MASS Concept of Operations to Support LG and OG User Profiles

The objective of the CONOPS is to provide a realistic scenario of logistics processes that will support the demonstration of the MASS functional capabilities. The CONOPS will be a document that will enhance the demonstration. The CONOPS has been broken down into time frames and describes the activities of Logistics Group (LG) and Operations Group (OG) personnel during the day as they perform their tasks.

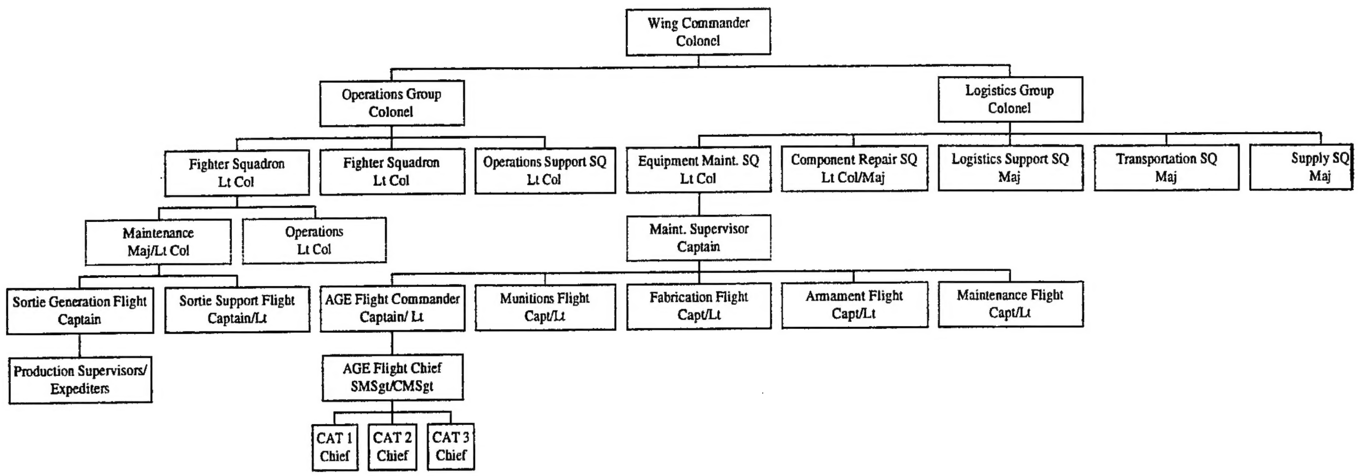
Background Information

The CONOPS is set in a timeline of activities involving an Equipment Maintenance Squadron's (EMS) Maintenance Supervisor Captain Smith (EMS/LGM), the Aerospace Ground Equipment (AGE) Flight Chief SMSgt Jones, and additional LG and OG personnel who are vital to aircraft sortie production. The scenario takes place on a combat ready F-16 Fighter Wing base. Management effectiveness requires timely information distribution, thus, the Squadron Commander (EMS/CC), Maintenance Supervisor (EMS/LGM), and Flight Chiefs generally hold meetings to review items such as aircraft status, supply status, deviations from previous day's/week's activities, and a look ahead at the projected flying schedules.

CONOPS Functional Description to support Squadron Maintenance Supervisor and Flight Chief User Profiles

This scenario is written from the Equipment Maintenance Squadron's Maintenance Supervisor's perspective. It is important to note that because of the MASS attributes described below, the SQ/LGM and Flight Chief would not only be finding new problems, but will be made aware of potential problems and those that are already being worked by their personnel. This is just one high level case in point, several other scenarios could be written! This scenario uses the Air Force Objective Wing organizational structure (figure 1).

Air Force Objective Wing Structure (Figure 1)



0700: EMS Maintenance Supervisor's Office

1. After looking at yesterday's flying schedule, Captain Smith moves on to look at what today has in store for the wing via his palm pilot. He displays the main status screen with icons for all of the squadrons that support sortie generation including 1st, 2nd, and 3rd Fighter Squadrons, Equipment Maintenance Squadron (EMS), and Component Repair Squadron (CRS) showing how many aircraft are scheduled to fly that day. Drilling into each fighter squadron icon, the Captain can quickly see the number of aircraft at home station, their status, location, ETIC, and programmed activity for today (scheduled maintenance, flyer, spare, etc).

2. Today, Captain Smith is particularly interested in his AGE Flight. Over the past few weeks he has noticed some trends in component malfunctions for his MASS carts. In addition, his AGE flight has been working diligently to obtain these parts from supply with very little success. His AGE flight has also had a high turnover of personnel over the past month and has not had the opportunity to thoroughly train its personnel. Thus, work prioritization has been a high management issue. Adding to his concern, the wing is scheduled to deploy two fighter squadrons back-to-back in support of in-theater operations in Southwest Asia this week...AGE will be a critical factor in accomplishing the aircraft launch.

0730: The Flightline

3. The 1st Fighter Squadron (1FS) production superintendent is having a meeting with his expediters when his palm pilot text pager goes off. He reads the text telling him that the AGE required to support the first few flying lines might be short, based on his pre-established threshold level. He sends a text message to the 1FS Combat AGE driver giving him a heads-up to the potential problem.

4. While driving on the flight line, the EMS/LGM receives a text page on his palm pilot. The page alerts the EMS/LGM that the AGE support for the flying schedule has fallen below the critical threshold of below 80% and is now in danger of impacting the operational mission. He then looks at the status of the entire AGE fleet status. Concerned about the potential impact, EMS/LGM calls the AGE Flight Chief and asks him to look into the problem.

0800: AGE Flight

5. SMSgt Jones, the AGE Flight Chief, informs the Combat AGE Team (CAT) Chiefs of the potential problems with this week's wing deployment, in addition to today's aircraft lineup. Using MASS's data retrieval capabilities to project AGE status and information, the CAT Chiefs use their palm pilots to read what situations exist with AGE currently on the flightline and AGE in work.

6. The AGE Flight Chief briefed Captain Smith and the EMS/CC that they are very quickly going to run into problems due to a lack of voltage regulators. Last night, the 2nd Fighter Squadron's (2FS) maintenance efforts fell behind schedule due to limitations on AGE availability. The supply supervisor informs the Supply Commander that voltage regulators have been a problem over the past few weeks and according to MASS fleet prognostics, five voltage regulators will be failing by next month at the current usage rate. The supply representative said they would contact the item manager to try and expedite the parts.

7. Captain Smith and SMSgt Jones quickly go through the rest of the areas on the Daily Recap and Today's Flying Schedule screens discussing all of the areas that MASS thresholds highlight as potential problems. The CAT chiefs state that they are working the MASS cart problems and expect to have a fix in the next few hours.

1030: AGE Flight

8. While in the AGE shop, the 1st Fighter Squadron (1FS) CAT chief wants to review the status of AGE currently on the flightline. Using his palm-pilot, he displays the real-time status of five MASS carts he has assigned to the 1FS. His particular interest lies in the voltage tracking and trending. He notices that one of the five carts has had irregular voltage surges over the past few hours. He shows the palm pilot screen snapshot to one of his technicians and radios the SQ AGE driver to bring the cart in for servicing.

9. While the cart was in for servicing, the technicians noticed corrosion on contact leads causing shortages in electrical current which also damaged several other smaller components. The corrosion was attributed to a slow leak in the battery housing that should have been cleared up by a Time Compliance Technical Order (TCTO) that was issued two weeks prior.

10. Upon hearing the new information regarding the corrosion, SMSgt Jones decided to have an immediate fleetwide re-inspection of MASS cart generator modules. The flight found three additional modules experiencing the same problems and were all fixed within three hours.

1200: Maintenance Supervisor's Office

11. Captain Jones and SMSgt Smith hear of the good news and the fully mission capability of their AGE Fleet and are reassured that next weeks wing deployment will occur with complete success. They depart the office for lunch and reflect on their day and how technology has finally started to live up to some of its promises to improve logistics. The end result of the MASS technology is just what the logisticians wanted— Right Information -- To the Right People -- In the Right Format -- At the Right Time.

List of Abbreviations/Acronyms

The following list represents the abbreviations and acronyms used in this document.

AFRL	Air Force Research Laboratory
AFB	Air Force Base
AGE	Aircraft Ground Equipment
AWM	Awaiting Maintenance
CND	Could Not Duplicate
CONOPS	Concept of Operations
CRS	Component Repair Squadron
DLR	Depot Level Reparable
EMS	Equipment Maintenance Squadron
EMS/LGM	Equipment Maintenance Squadron Maintenance Supervisor
ETIC	Estimated Time In Completion
FMC	Fully Mission Capable
FW	Fighter Wing
HESR	Human Effectiveness Directorate, Deployment and Sustainment Division, Logistics Readiness Branch
LG	Logistics Group
LG/CC	Logistics Group Commander
LGCD	Logistics Group Deputy
LIMFAC	Limiting Factors
LRU	Line Replaceable Unit
MDS	Mission, Design, Series
MICAP	Mission Capability
MOC	Maintenance Operations Center
MPC	Mobility Processing Center
MSGT	Master Sergeant

NCO	Non-Commission Officer
NCOIC	Non-Commissioned Officer in Charge
NMC	Not Mission Capable
NMCS	Not Mission Capable Supply
NRTS	Not Reparable This Station
NSN	National Stock Number
OG	Operations Group
OG/CC	Operations Group Commander
PMC	Partially Mission Capable
PMEL	Precision Measurement Equipment Laboratory
R&D	Research and Development
SBSS	Standard Base Supply System
SMO	Squadron Maintenance Officer
SMSgt	Senior Master Sergeant
SQ	Squadron
USM	Unscheduled Maintenance
UTC	Unit Type Code
WG/CC	Wing Commander